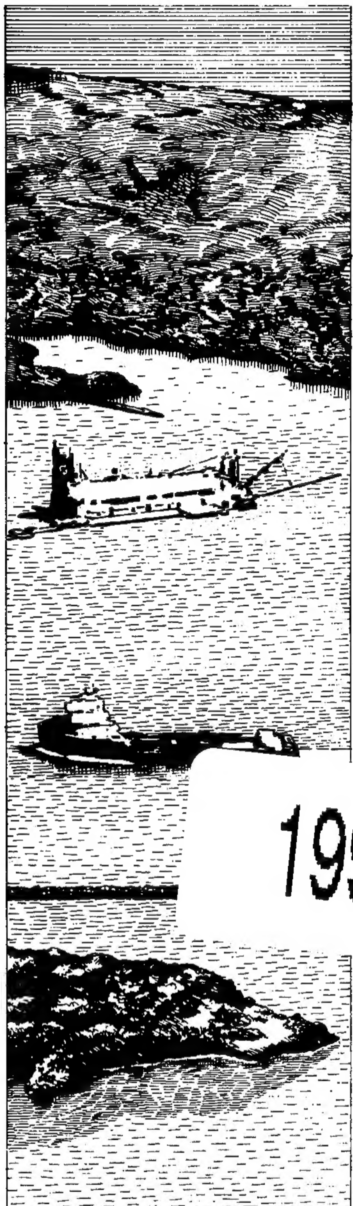
US Army Corps
of Engineers



DREDGING RESEARCH PROGRAM

TECHNICAL REPORT DRP-95-8

DREDGING RESEARCH PROGRAM BENEFITS ANALYSIS

by

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September 1995

Final Report

Approved For Public Release; Distribution Is Unlimited

Prepared for DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

Under DRP Technical Area 5

The Dredging Research Program (DRP) is a seven-year program of the US Army Corps of Engineers. DRP research is managed in these five technical areas:

- Area 1 - Analysis of Dredged Material Placed in Open Waters
- Area 2 - Material Properties Related to Navigation and Dredging
- Area 3 - Dredge Plant Equipment and Systems Processes
- Area 4 - Vessel Positioning, Survey Controls, and Dredge Monitoring Systems
- Area 5 - Management of Dredging Projects

US Army Corps of Engineers
Waterways Experiment Station

Dredging Research Program Report Summary

"Dredging Research Program Benefits Analysis" (TR DRP-95-8)

ISSUE: The Dredging Research Program (DRP), 1988-1994, was a major research and development program that addressed problem areas related to the physical and managerial aspects of the U.S. Army Corps of Engineers dredging mission. The benefits derived from actual or proposed use of DRP products need to be quantified.

RESEARCH: Every product of the DRP was catalogued. Visits were made to 21 Corps Districts or Divisions to interview dredging operations and maintenance personnel regarding use or potential use of DRP products and the benefits derived or expected to be derived by such use. The benefits were catalogued and arranged into a database that was used to analyze the benefits.

SUMMARY: The U.S. Army Corps of Engineers is involved in virtually every navigation dredging operation performed in the United States. The Corps dredging mission entails maintenance and improvement of 25,000 miles of commercially navigable channels serving over 400 ports, including 130 of the Nation's 150 largest cities. Dredging is the single most costly item in the Corps of Engineers' Civil Works budget resulting in a current (1994) expenditure level for maintaining existing projects of $400 million per year. In addition, recent authorized improvements to U.S. waterways call for new work dredging by the Corps that will demand an average expenditure of $200 million annually for the next 7 or 8 years.

In 1988, the U.S. Army Corps of Engineers launched the Dredging Research Program (DRP), a 7-year research and development program to address problems and needs arising in the performance of its dredging mission. Managed at the U.S. Army Engineer Waterways Experiment Station (WES), the objective of the DRP was to reduce the cost of dredging to a minimum consistent with mission performance and environmental responsibility. To effectively accomplish this objective, the DRP was divided into five technical areas that address problems related to physical and managerial aspects of dredging or dredging projects.

The cost for the DRP in 1994 dollars was $44 million. In 1993, a study was implemented that measured the economic benefits derived from actual or proposed use of DRP products. Results of this study indicate that there is a 0.90 probability that the DRP will provide benefits (in 1994 dollars) of at least $100,586,000 from 1994 through 1998. This report documents the study methodology used to obtain the estimated economic benefits of the DRP.

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Dredging Research Program

Technical Report DRP-95-8
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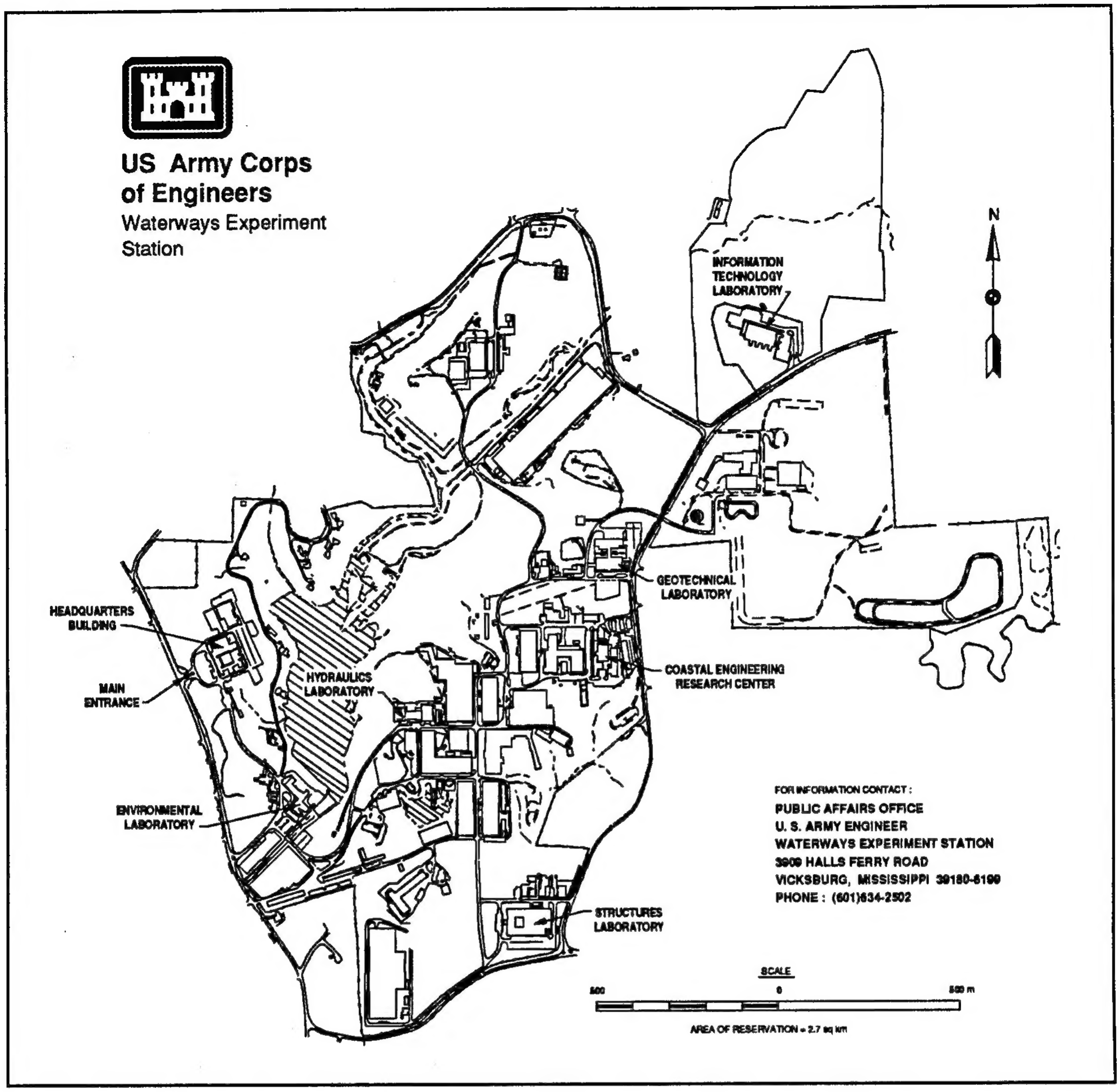

Waterways Experiment Station Cataloging-in-Publication Data

Dredging Research Program benefits analysis / by F.H. (Bud) Griffis ... [et al.] ; prepared for U.S. Army Corps of Engineers.
97 p. : ill. ; 28 cm. -- (Technical report ; DRP-95-8)
Includes bibliographical references.
1. Dredging -- Research. 2. Dredging -- Cost effectiveness. I. Griffis, F. H. II. United States. Army. Corps of Engineers. III. U.S. Army Engineer Waterways Experiment Station. IV. Dredging Research Program (U.S.) V. Series: Technical report (U.S. Army Engineer Waterways Experiment Station) ; DRP-95-8.
TA7 W34 no.DRP-95-8

Contents

Preface

This document was produced by the Coastal Engineering Research Center (CERC) of the U.S. Army Engineer Waterways Experiment Station (WES) during the period January 1993 to April 1994. The study was sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), as a part of the Dredging Research Program (DRP), Work Unit No. 32492, "Technology Transfer," managed by CERC. HQUSACE Technical Monitor for DRP Technical Area 5, Dredging Management, and later Chief Technical Monitor was Mr. Barry W. Holliday.

The report was prepared by Drs. H. F. Griffis and Sortris Pagdadis, and Mr. Charles Jettmar of Columbia University, New York, and Mr. Russell K. Tillman of the Program Management Office, CERC.

The study was conducted under the general supervision of Dr. James R. Houston, Director, CERC; and Mr. Charles C. Calhoun, Jr., Assistant Director, CERC. Mr. Thomas W. Richardson, CERC, was Manager of DRP Technical Area 5. Principal Investigator was Mr. Russell K. Tillman. Program Manager for the DRP was Mr. E. Clark McNair, Jr., CERC. Dr. Lyndell Hales, CERC, was assistant Program Manager.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Summary

Benefits of the Dredging Research Program

Results of the study

There is a 0.90 probability that the Dredging Research Program (DRP) will provide benefits of at least $100,586,000 from 1994 through 1998. Based on one-time noncyclical project benefits that were not included in that number, it is probably understated by 100 percent.

A first in the U.S.

This benefit analysis is the first detailed study to accurately quantify and document economic benefits to the user community of a Federal research and development program. Early in the study, a literature review revealed that the methodology to quantify the economic benefits of research and development programs does not exist.

Patterned after the private sector

This study was keyed to techniques used by businesses to predict sales revenue. Forecasting sales prior to starting a venture allows firms to estimate potential profit by subtracting expenses from anticipated revenue. These sales-forecasting techniques were applied to identify and quantify in dollars the benefits of Corps-wide use of DRP products. To obtain this forecast (sales estimates), personnel in a majority of Corps' Division and District offices with dredging programs were interviewed to determine actual and anticipated DRP product use. To estimate benefits, Corps dredging projects were evaluated with and without DRP products.

Adjusting for uncertainty

In calculating the benefits associated with a specific DRP product, there are a considerable number of uncertainties in the estimate. There are the values

used in the estimate itself, the actions that may occur between the time of the estimate and the execution of the project, and the actual performance of the DRP product. To account for these uncertainties, a stochastic simulation approach was used. Rather than use a single point estimate for the benefits, an estimate for which there is a 90-percent confidence level that the benefits will be exceeded was chosen. Rather than say an economic benefit is equal to a certain estimate, the authors have chosen to say that the benefit is greater than or equal to a certain estimate.

Conservative estimate

A computerized Monte Carlo simulation, skewed to the low side, allowed uncertainty and conservative benefits to be incorporated into the benefit estimates in a conservative manner consistent with standard prudent practices. The end product of this simulation was a range of dollar savings associated with DRP economic benefits. Figure 7 in the main text of this document (page 37) is a relative frequency histogram of estimated annual Corps Operations and Maintenance (O&M) savings. Mean expected annual benefits are $13,992,000. However, the number used in this study is not the mean value but a value of $11,200,000, for which there exists a 90-percent confidence of exceedance.

Broad range of benefit types

During this study, the following types of benefits were identified for new work and maintenance dredging projects:

a. *Direct cost benefits*. Benefits that result directly from the use or influence of DRP products versus the cost of the next available alternative. Example: Using DRP modified draghead to dredge stiff and compacted clays and sands versus traditional draghead designs.

b. *Cost avoidance benefits*. Labor, equipment, or legal costs prevented by the use or influence of DRP products. Example: Using the DRP Silent Inspector to monitor dredging operations to ensure contract obligations were successfully accomplished.

c. *Environmental enhancement benefits*. Benefits that result from performing dredging operations in an environmentally positive manner or by simplifying or standardizing requirements through the use or influence of DRP products. Example: Using DRP open-water site-management strategy to effectively ensure that environmental concerns and site strategies were met.

d. *Mission and efficiency enhancement benefits*. Benefits that the Corps receives by using state-of-the-art technology to perform the dredging

mission. Example: Using DRP acoustic impedance technology to accurately identify subbottom conditions.

e. Indirect cost benefits. Benefits that are a higher-order consequence of using DRP products. Example: Benefits associated with keeping a port in operation by continued dredging allowed because DRP technology helps keep a disposal site open. These benefits are so large as to overshadow other calculated benefits. Because of their size, uncertainty, and, in some instances, difficulty of acceptance, indirect benefits have been mostly omitted from this report.

All DRP benefits could not be quantified. Over 95 separate benefits identified during Corps interviews were not quantified because present methods are not adequate to provide results that can be mutually agreed upon. For example, what are the dollar benefits associated with the DRP hopper dredge draghead design and its reduction of sea turtle mortalities? However, it is apparent that such unquantified benefits do facilitate or enhance execution of the Corps' national dredging program. Therefore, they are documented in the report but are treated separately in order not to reduce the confidence level of the benefit totals.

Limitations of the Study

Time constraints made it impossible to interview all Corps Division and District offices with dredging programs. However, this study does incorporate input from the 18 Districts that perform the bulk of the Corps dredging program. No attempt was made to adjust benefit totals to estimate for input from non-interviewed sources.

Only those future uses of DRP products specifically identified during interviews were incorporated into estimates. Other uses that are presently unanticipated will likely develop as DRP products transition into everyday practice.

This was a first-time effort to estimate the economic benefits of a research and development program. As such, it reflects the lack of established procedures and guidance. Hopefully, the techniques applied and experiences gained in executing this study can form a basis for such standardization.

Assumptions were necessary to adjust for uncertainty in the benefit projections. While the accuracy, sensitivity, and impact of these assumptions can be debated, they were patterned after well-known procedures used by the private sector in similar situations. Due to the way in which this study was conducted, the benefit estimates can be re-examined at a later date to provide improved feedback on such assumptions for use in future studies.

1 Introduction

During Fiscal Year (FY) 1988, the U.S. Army Corps of Engineers (USACE) launched a major research and development program to address problems and needs arising in its dredging operations. This effort, the DRP, is a major thrust toward developing improved technologies that can reduce the costs of dredging operations. While the DRP focuses on problem areas related to the physical and managerial aspects of dredging or dredging projects, it does so with an awareness of the Corps' environmental responsibilities.

Corps' Dredging

The USACE Directorate of Civil Works is involved in virtually every navigation dredging operation performed in the United States. The Corps dredging program is the principal factor in the maintenance and improvement of 25,000 miles of commercially navigable channels serving 400 ports, including 130 of the nation's 150 largest cities. The waterways connecting the nation's ports and harbors handle about 2 billion tons of commerce each year, as waterborne transport continues to be the most cost-and energy-efficient means of shipping bulk cargoes such as coal, grains, petroleum products, chemicals, ores, and finished metal products. This commerce is vital to the economic prosperity of the United States; roughly 20 percent of all jobs in this country depend in some way on waterborne commerce. In addition, the waterways network constitutes an infrastructure component essential to the nation's defense capabilities.

Dredging is the single most costly item in the Corps' Civil Works O&M budget. To maintain and operate the nation's existing navigation system, the Corps of Engineers dredges an average of 250 to 300 million cu yd of sediment at a current (1994) expenditure level of about $400 million per year. Further, recently authorized improvements to U.S. waterways call for new work dredging by the Corps that will demand an average expenditure of $200 million annually for the next 7 or 8 years. The Corps also directly supports the U.S. Navy's dredging programs in both maintenance and new work projects.

Need for Research

Though the Corps has been actively involved in dredging for over 160 years, this responsibility has experienced dramatic changes in its relationship with other interests, its means of execution, and in the variations of dredging workload. Significant changes in the conduct of dredging operations and in the coordination of such operations with other interests resulted from the National Environmental Policy Act of 1969 and subsequent Federal and non-Federal legislation. The means of executing Corps dredging, particularly that portion requiring hopper dredges, changed significantly as the bulk of such work shifted from the once-large Corps fleet to contract hopper dredges. A long period in which Corps dredging was almost totally one of maintaining existing waterways and harbors ended with passage of the Water Resources Development Act of 1986. This legislation authorized major improvements to many existing navigation projects.

Future changes in dredging are not expected to be any less dramatic than those in recent years. The Corps will be continually challenged in pursuing optimal means of performing its dredging as government seeks to reduce budget deficits and as non-Federal interests assume a greater share of the financial burden for improving and maintaining navigation projects. However, these challenges provide vast opportunities for both government and the private sector to seek innovative means to serve the nation's needs. To fully exploit these opportunities, the Corps must enhance its recognized expertise in the operational aspects of dredging. Implementation of a large applied research and development program to meet the demands of changing conditions and to generate significant technological advances and new directions that will be adopted by all dredging interests is one means of achieving this goal. The Corps took similar action in response to the environmental concerns and pressures of over two decades ago; the result was a position of world leadership in the environmental aspects of dredging that continues today.

Dredging Research Program

Goals

The stated objective of the DRP is to reduce the cost of dredging consistent with mission performance and environmental responsibility. This objective can be accomplished in a variety of ways, including, but not limited to, the following:

a. Increasing the efficiency of a process, operation, or of equipment.

b. Reducing the number and impact of contract claims.

c. Defining and communicating operational requirements comprehensively and accurately.

d. Sharing user's successes in reducing costs, and modifying or expanding them into Corps-wide applications.

In addition to the primary goal of saving Federal funds, the DRP performs important secondary functions, such as:

a. Serving as a focal point for technological advance in dredging by bringing together representatives of the Corps, other government agencies, the dredging industry, universities, private research organizations, engineering consultants, and foreign interests in a synergistic relationship.

b. Making cost-sharing partnerships more credible by increasing the confidence that participants will obtain effective returns on their dredging investments.

c. Increasing the feasibility of cost-sharing projects by reducing the cost of dredging.

d. Increasing the competitiveness of U.S. ports and the U.S. dredging industry in the world marketplace.[1]

Technical areas

The DRP consisted of five technical areas. These areas and their respective objectives are:

a. *Technical Area 1.* Analysis of dredged material disposed in open waters.

(1) Better calculation of boundary layer properties for analyzing behavior of open-water disposal areas.

(2) Acquisition of field data sets for input to improving the calculation of boundary layer properties.

(3) Improvement of computational techniques to predict the short- and long-term fate of dredged material.

(4) Collection of data for input to improved simulation methods and development of improved site monitoring techniques.

b. *Technical Area 2.* Material properties related to navigation and dredging.

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1 Russell K. Tillman. (1991). Memorandum to DRP Program Manager, *An approach to determine Dredging Research Program cost savings.*

(1) Development of instrumentation and operating procedures for rapid surveys of fluid-mud properties.

(2) Definition of navigable depth in fine-grained sediment.

(3) Development of instrumentation for analyzing properties of consolidated sediments.

(4) Establishment of dredging-related soil and rock descriptors.

c. *Technical Area 3.* Dredge plant equipment and system processes.

(1) Improved draghead design for various conditions.

(2) Improved eductors for sand bypassing.

(3) Increased dredge payload for fine-grained sediments.

(4) Design portable single-point mooring buoy for hopper dredge direct pump-out.

d. *Technical Area 4.* Vessel position, survey controls, and dredge monitoring systems.

(1) Development of real-time system for measuring project-site tide and wave conditions in offshore open waters.

(2) Development of a three-dimensional positioning system for dredging and disposal and hydrographic surveying operations using the differential global positioning system (DGPS) satellite constellation.

(3) Evaluate production meters used in various dredging situations.

(4) Assemble new systems for real-time monitoring of draft and sediment densities in hopper loads and dump scows.

(5) Develop unmanned inspection, monitoring, and reporting system for use on hopper dredges.

e. *Technical Area 5.* Management of dredging projects.

(1) Develop a comprehensive model of dredging project activities that can evaluate the effects of decisions and project changes.

(2) Develop guidance for optimizing use of open-water disposal sites.

(3) Perform analysis of cost-estimating techniques for dredging.

(4) Prepare Engineer Manuals incorporating state-of-the-art dredging technology.

(5) Develop procedures for managing open-water disposal sites.

Work unit selection

When the DRP was started, a basic work unit (the level of funded research work) selection philosophy was embraced. The objectives of each technical area were expressed through work units. No work unit would be funded if it did not, in the opinion of the program manager, technical area manager, or Corps-wide Field Review Group, (FRG), have a strong potential for cost savings (consistent with mission performance and environmental responsibility) once the research and development products were implemented.

Purpose and Scope

The major purpose of this report is to present the results of an analysis of economic benefits attributable to the DRP. This analysis can be used for a variety of management purposes, including the obvious one of assessing how well the DRP has achieved its principal objective. For this study, each product of the DRP was catalogued. Each O&M dredging project for a 4-year period ending in 1993 was analyzed to determine whether a product of the DRP was used on the project and whether there was a potential for use of a DRP product. If a product was used or had the potential to be used, then the expected benefit of using the product was estimated. The benefits were categorized as direct benefits, cost avoidances, environmental enhancements, mission enhancements, and indirect benefits. These benefits were arranged into a database. The uncertainty associated with each benefit estimate was assumed to be captured by a specific estimate probability distribution. The sum of all benefits was then subjected to a Monte Carlo analysis and the relative frequency histogram of the final sum of all benefits was calculated.

DRP technology use by all Districts is not represented within this report. Due to the limited duration of the analysis, it was not possible to contact all District or Division staff who have had actual or, more importantly, could have potential uses for DRP products. Consequently, a number of Districts did not have any benefits assigned. To address this problem, the benefits analysis team originally proposed to estimate benefits by extrapolation for all Districts or Divisions that did not have any actual calculated benefits. The extrapolation would have been based on the assumption that a given District's overall DRP attributable benefits would be proportional in magnitude to its workload. Since the actual quantified DRP benefits produced no correlation with District O&M budget levels, no extrapolation could be produced. Of the 31 Districts with regular dredging programs, 21 were included in the study. The other 10 were generally inland Districts with smaller riverine dredging workloads. Yet their benefit from the DRP could be close to that of similar Districts

considered in the study. Due to the absence of these Districts' influences, the overall benefit levels produced by this analysis should be considered understated or conservative. Once technology transfer reaches a steady-state condition, a stronger correlation between benefits and workload should be evident.

At the onset of this study, it was intended to attempt to quantify environmental benefits of the DRP. Although the DRP has been responsible for considerable environmental enhancements, the benefits associated with such enhancements are primarily intrinsic in nature, and the authors felt that this report would better serve its purpose by pursuing the more directly quantifiable benefits associated with the DRP. However, Section 10 presents a comprehensive bibliography of procedures for quantification of environmental benefits that was compiled as guidance for future research.

2 Study of Economic Benefits

Objective

This study was designed to produce (on a work unit product basis) an accurate assessment of actual and potential economic benefits to the Corps from the implementation of DRP products. In addition to reductions in direct costs, it also considered avoided costs, additions to mission capability, enhanced environmental credibility, increased regulatory efficiency, and improvements in the quality of dredging.

Approach

The authors conducted an exhaustive literature search for other studies or methods to use as models, but none could be found that would accomplish the objectives of this study. The only published effort to quantify benefits derived from research projects was done by the Gas Research Institute (GRI).[1] Their approach was purely subjective and therefore not applicable.

Figure 1 outlines the approach that was proposed at the beginning of the study. A series of meetings were held with the FRG and the DRP staff at the U.S. Army Engineer Waterways Experiment Station (WES) to review the plan. This approach was acceptable with the provision that the approach might be amended if indicated by information derived from interviews and questionnaires.

There are two options available to approach a benefits analysis study. One could start at the macro level and try to find a general method to estimate the overall benefits of the DRP; or one could compute expected benefits at the project level, and then find a method to synthesize the results. This study used the latter, because no national theory exists to justify the macro approach.

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1 The Gas Research Institute 1981, 1982, 1983, 1984, 1985, 1986, and 1987 Appraisal Results Reports, and Project Appraisal Methodology: Summary of Application to GRI 1980 Program.

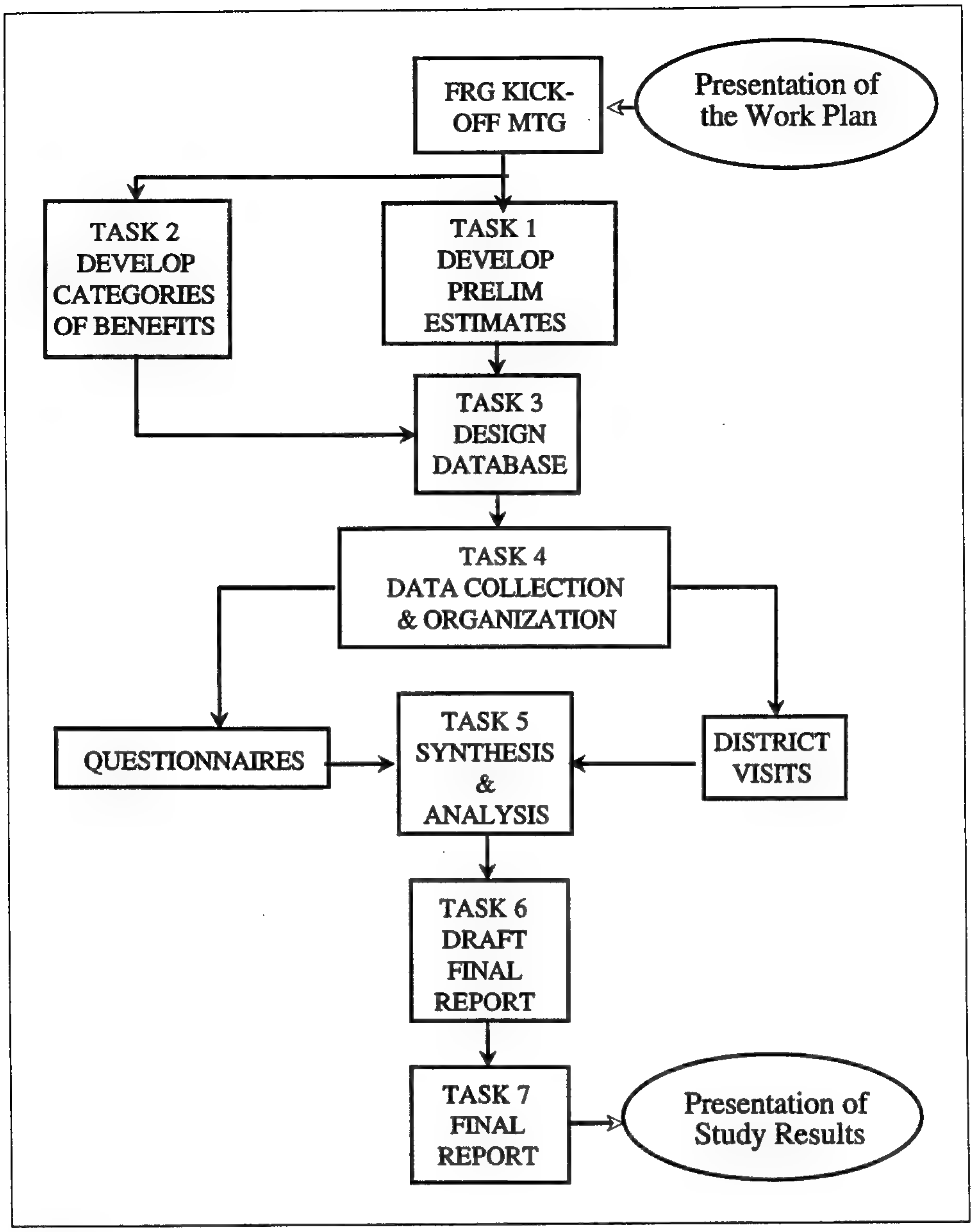

Figure 1. Outline of approach

3 Task 1: Develop Preliminary Estimates

Using the knowledge and background of the DRP principal investigators (PI's), statements of the utility and benefits of the work unit products were developed. Since the PI's were scientists and engineers unaccustomed to estimating detailed costs, the statements were more qualitative than quantitative. The following paragraphs list products and potential benefits.

Technical Area 1

PLUMES (PLUme MEasurement System). PLUMES is an acoustic system used to measure fluid velocities and suspended sediment concentrations of material at dredging or disposal sites. The sensor is a commercially available broad-band acoustic doppler current profiler. Direct benefits could consist of simplified environmental monitoring procedures. Also, major benefits have resulted from the ability to demonstrate scientifically to resource agencies that suspended sediments from dredged material disposal operations would not be dispersed into environmentally sensitive areas, thus allowing the continued use of disposal sites off Miami, FL, and Tyler's Beach, VA.

PC program for predicting the short-term fate of dredged material (STFATE). This PC-based model, refined under the DRP, calculates suspended sediment concentrations following disposal of dredged material from a barge, pipeline, or hopper dredge. The model also computes the bottom footprint (area and thickness) of the disposed dredged material mound resulting from a single disposal operation. A second program simulates multiple disposal operations to show the time-varying creation and transport of material from a full-sized mound. Benefits may result when the model is used to determine the need for additional testing in disposal operations permitted under Sections 103 and 404. Use of the model has allowed the continued use of open-water sites in Puget Sound and other locations. Potential benefits from being able to use existing sites close to dredging projects (as opposed to distance placement alternatives) are very high.

PC program for predicting the long-term fate of dredged material (LTFATE). This PC program computes the long-term stability of a dredged material disposal mound by calculating the time evolution of the mound as a function of waves, currents, depths, and bottom geometry. Application of this model is critical for predicting the stability of capped contaminated sediment mounds and sites. Use of the model has allowed the continued use of open-water sites in New York and other locations. Potential benefits are great.

Empirical guidance on predicting physical fate of dredged material (EBERM). This PC program predicts the fate of dredged material to be placed in an open-water site based on knowledge gained from monitoring similar sites. The stability of dredged material mounds can be evaluated as a function of mound height, water depth, and predicted bottom wave-orbital velocities (based on predicted return frequencies). Empirical guidance based on the results of this evaluation can then be used to predict whether or not a disposal mound is likely to erode, migrate, or be stable. Use of this program can result in manpower savings by allowing quick and rapid assessment of the potential stability of a mound early in project planning. Also, major benefits attributable to reduced haul distances or elimination/avoidance of onshore disposal are possible.

Technical Area 2

Fluid mud survey system. This product is a non-acoustic system that measures the density of fluid mud. It is applicable for use in the Gulf of Mexico, southeastern Atlantic, and other fluid mud areas. Major direct benefits and cost avoidances could result when the product is used to determine whether contractor claims for payment are fair and equitable. In certain situations, it will also reduce the scope of the dredging project. Cost avoidances could also be derived from a reduction in related contractor claims, reduction in prior survey time, and validation of acoustic survey results.

Towed body. The towed body is a part of the fluid-mud survey system and is applicable for use in the Gulf of Mexico, southeastern Atlantic, and other fluid mud areas. It is a moving gauge that tracks a continuous horizon of density for assessing the navigable depth of channels with fluid-mud conditions. Direct benefits could result from the reduced manpower and equipment needed to perform these tasks. The product could also be used as a source for determining whether contractor claims for payment are fair and equitable.

Rapid measurement of consolidated-sediment properties. This product is an acoustic-based system that accurately measures the thickness of different subbottom sediment layers. Direct benefits can result from continuous coverage of bottom and subbottom conditions to provide accurate information for optimum boring placement. Environmental enhancements could be derived from the accurate delineation of cultural resources and long-term monitoring of disposal berms. Mission enhancements could result from improved predictions

of slope stability, location of under-channel utilities, and determination of fluid-mud-zone thickness. Costs could be lowered by reducing contractor material claims and associated material changes, and by reducing the number of borings and changes in channel routing to avoid undesirable conditions. Other nondredging applications of this technology may involve the ability to locate and assess the condition of articulated concrete mattresses and the determination of navigable depth.

Drilling Parameter Recorder (DPR). The DPR is an instrumentation and data acquisition system that provides a continuous record of drill rig operational parameters that relate to rock material properties. An additional product of this system is the correlation of these parameters with the unconfined compressive strength of rock. Direct benefits may result from the ability to drill roller bit holes versus the more expensive cored holes. Mission enhancements may result from improved procedures in locating strata elevation compared to current Corps procedures. With the DPR, one can tell (vertically) where the cores came from, resulting in a cost reduction for a given number of bore holes. The DPR could also assist in avoiding claims frequently encountered when rock is present at dredging projects.

Point Load Test for dredged material strengths. Procedures have been developed for point load testing of weak or saturated rock using easily portable equipment. A point load test (PLT), performed onsite, can obtain a strength index correlated to unconfined compressive strength (UCS), resulting in more complete information that allows for more efficient planning and improved project design. Direct benefits may also come from PLT to UCS correlations because some 400 tests in a computerized database system, called PLUCS, will provide a sample space for determining strength for a wider spectrum of site materials. Use of PLUCS could also result in better contract specifications. The PLT and PLUCS may also produce cost avoidances by verifying site conditions as stated in contract specifications.

Technical Area 3

Improved draghead design. Laboratory and field-tested design recommendations for trailing suction draghead modifications were implemented to increase production when dredging compacted fine sands. Modifications to prevent sea turtles from being entrained into the dragheads have also been investigated. Direct benefits may include 10- to 25-percent increased production in compacted fine sand and stiff clays. Environmental enhancements may result from reduced sea turtle mortalities. Reduced mortalities in turn may eliminate or reduce environmental windows that restrict dredge operating periods and the need for environmental monitoring during dredging operations.

Hydraulic design guidance for fluidizers

This product is a report that describes the hydraulic design of fluidizers for sand bypassing, both as supplements to an eductor-based system and as stand-alone systems for a small inlet. Direct benefits may result from fluidizers increasing the capture area and amount of sand bypassed by 50 to 100 percent. They may also be able to greatly reduce dredging requirements for selected small inlets.

Eductors. A royalty-free eductor was developed that is easy to install and operate because of improved resistance to debris. The final product will be plans and specifications for the eductor. Direct benefits may result from pumping efficiencies that are 10 to 30 percent greater than other eductors.

Submersible pumps. Testing under the DRP has shown that commercially available submersible pumps have applications for bypassing sand and for maintaining navigation locks. Direct benefits may result from more efficient allocation of hydraulic plant stand-by time and rapid and effective short-notice responses for siltation removal. The pumps can also be used for dewatering, cleaning off boat ramps, and unsticking lock gates.

Increasing hopper loading of fine-grained sediment. A number of devices, including hydrocyclones and inclined plates, were laboratory tested to investigate their potential to increase the load of fine-grained material retained in a hopper. While they were not found to be feasible in prototype form, the tests provided valuable information on applying this technology to other areas of dredged material management such as the operation of confined disposal facilities.

Guidance and specifications for hopper monitoring

This work unit developed a system of using electronic sensors to measure the amount of material in a hopper and to correlate that to hopper load. Possible direct benefits include measurement-time reduction of about 1/2 hr per 24-hr day. Cost avoidance is also possible because the system reports the volume of material dredged and transported, an independent verification of load that might result in claims reduction. Lastly, mission enhancements may result from interfacing other sensor measurements with the load-measurement system, thus bypassing human factors to improve accuracy.

Resistivity to determine density in hopper loads. A series of sensors are deployed on a pipe in a hopper to measure resistivity of dredged sediment. By correlating resistivity to density, an estimate of the hopper load can be calculated. A pore-water sensor that collects information to determine conductivity as a function of salinity has also been developed. Direct benefits may result from improved accuracy in measuring hopper load, allowing for more reliable contractor payment. Mission enhancements may result from an automated hopper-load that produces an improved economic load for overflow dredging.

Single-point pumpout buoy conceptual design. A conceptual design was developed for a portable single-point buoy for hopper dredge direct pump-out. The buoy is easily transported by barge, truck, or rail and can be installed with a minimum of lifting capability. Direct benefits may result from savings in project design time and less costly sediment transfer versus material rehandling. Environmental and mission enhancements may result from increased wetland and beach renourishment, as well as rapid response to emergency operations such as post-hurricane reconstruction efforts.

Water Injection Dredging (WID). WID is an innovative approach to dredging based on a simple concept: when shoal sediment is fluidized, it flows by force of gravity to deeper areas where it does not affect navigation. To accomplish this effect, large volumes of low-pressure water are injected into the sediment through a row of jets in a horizontal pipe. The pipe is at the end of a vertically swiveling arm mounted on the dredging vessel. WID technology was demonstrated by the DRP at two locations on the Mississippi River in 1992. These demonstrations showed that WID has the potential to lower dredging costs significantly when used in the correct conditions (silt and fine sand or coarse sand with nearby deep water). In addition, the lack of an active cutter head means there is minimal danger to structures, pipelines, and utility cables, and that dredging can be performed in areas not previously possible. Lastly, lack of a discharge pipeline results in minimum interference with navigation.

Technical Area 4

Production meter user guidance. The result of this research consists of technical information on selecting, installing, and using a nuclear dredge production meter system. By using production meters efficiently, dredge operators can improve overall dredge performance and contribute to an improved database for the dredge and associated equipment. The system also can be used to calibrate nonnuclear meters. Direct benefits may result from the ability to determine operating characteristics of a dredge or to optimize dredge production.

Automated Real Time Tidal Elevation System (ARTTES). ARTTES was developed to measure, quality-check, and transmit to an unlimited number of receivers real-time water level data for all locations within a designated offshore area. This system allows for more accurate dredging and hydrosurvey operations and minimizes the amount of over-depth dredging necessary to achieve design channel depths. While ARTTES benefit potential is site-specific, it can be easily quantified, and use of the product may prevent a significant amount of unnecessary dredging. It results in a reduction in allowable overdepth as the real-time tide can be better incorporated into dredging operations. Lastly, cost avoidances may occur with a reduction in changed or differing site condition claims.

Vertical motion measurement system. The vertical motion measurement system was specifically developed for offshore operating environments involving small vessels and short-period waves. The system determines the vertical motion at sounding transducer positions. The product increases the accuracy of survey systems and expands the weather window, allowing survey crews to work in rougher waters. Direct benefits could result from the product's lower procurement costs versus the costs of a more expensive commercial system.

Sea state indicators. This product estimates local wave height and period (sea state) for design, monitoring, or contract administration of dredging projects. Cost avoidances may be derived from potential elimination of unsubstantiated contractor claims for downtime resulting from bad weather. The product could also serve in verifying claims on whether sea state and weather were extreme enough to stop dredging operations.

Silent Inspector. Plans and specifications for the Silent Inspector provide an automated system that significantly improves monitoring and management of dredging operations on hopper dredges. The Silent Inspector uses existing sensors and navigation/position information to determine and maintain a time history of the state of dredge operations. Direct benefits can result from contract inspection manpower savings and from providing the necessary detailed information to ensure that the obligations of the contract were successfully met. Additionally, there is a major potential for using Silent Inspector data to extend the life of disposal sites through more efficient dump placement. Lastly, it can be used as a means of monitoring environmental compliance during dredging operations.

Technical Area 5

Design of nearshore berms. The DRP developed design guidance for construction and evaluation of nearshore berms using dredged material, including effective placement of the material in the nearshore zone. Potential cost benefits are derived from (a) reduced haul distance resulting from near-by berm placement, (b) beach nourishment that is a beneficial use of dredged material, and (c) storm protection because of wave attenuation by the nearshore berm. Also, there may be environmental enhancements derived from nearshore berms providing fisheries habitats.

Capping technologies. This research will produce methodology that includes specifications for subaqueous disposal and isolation of contaminated dredged material including site characteristics, construction methods, long-term maintenance, and monitoring of capped sediments. Potential direct benefits and cost avoidances for this effort could be very large. This work will help make capping a scientifically accepted alternative for disposal of contaminated dredged material. Direct benefits could be realized by considering that capping costs are $3 to $10 per cubic yard versus alternative disposal methods for

contaminated sediment ranging from thirty to several hundred dollars per cubic yard.

Hopper dredge engineering manuals. An Engineer Manual that provides instruction for hopper dredge operations and standard report procedures is being produced by the DRP to supersede the version in current use, which dates back to 1953. The revised edition will update guidelines and be more understandable, comprehensive, and relevant for present day hopper dredge operations.

Open-water disposal site management. A management strategy for developing a long-term plan for open-water disposal sites was developed by the DRP. The strategy assembles into a useable tool the various DRP-produced successes throughout the Corps. Direct benefits of this strategy include extending usable site life and improving design process efficiency. The product also reduces the chance for misapplication of site-management technology, which may result in increased credibility with resource agencies.

Combined product influence effects. During the District-visit phase of this benefits analysis study, several potential benefits were identified by both WES and District personnel that could result from a combination of two individual DRP products. No benefits were quantified for these cases because the products themselves have yet to be developed. Three specific examples of possible future benefits from a combination of DRP products are:

a. The acoustic profiler and fluid-mud constant density definition products could be used to maintain consistent hydrographic survey operations. The Savannah District expressed a need for this type of product to allow better determination of sediment quantities, classifications, and dredgeabilities.

b. Combined short- and long-term fate numerical modeling programs could be used to help facilitate berm placement. Several Districts, including Seattle, have expressed interest in using this proposed product.

c. Synergistically combining all DRP products within site-management methodology was identified as being useful in maintaining open-water disposal of dredged material in politically, socially, and economically constrained sites. Discussions occurred with the San Francisco and New York Districts and with the New England Division.

4 Task 2: Develop Categories of Benefits

Based on discussions with WES staff and District personnel and on the experience of the benefits analysis team, categories of benefits were first defined and then refined to reflect DRP product application. Definitions and categories of DRP economic benefits follow.

Direct Cost

Direct cost benefits are economic benefits that result directly from the use or influence of one or more DRP products versus alternatives for operations and maintenance and/or new work projects. These benefits generally result from:

a. Reduced cycle time for dredging operations.

b. Reduced design and overhead expenses.

c. Improved productivity of operations.

d. Extended disposal site life.

e. Reduced or eliminated excessive dredging cycle/time.

f. Reduced subsurface exploration.

g. Reduced hopper load measure time.

h. Reduced survey and positioning mobilization.

i. Reduced or eliminated monitoring and administration.

j. Reduced physical plant expenses.

k. Reduced onshore material placement.

l. Increased beneficial uses of dredged material.

Cost Avoidance

Cost avoidance benefits are labor, equipment, or legal costs prevented as a result of the use or influence of one or more DRP products. These benefits generally result from:

a. Reduced or eliminated legal expenses due to differing site claims.

b. Reduced or eliminated added expenses due to faulty survey.

c. Eliminated job operational error.

Environmental Enhancement

These are economic benefits from performing dredging operations in an environmentally satisfactory manner or from the simplified or standardized regulatory process facilitated by the use or influence of one or more DRP products. Some potential benefits may result from:

a. Reduced District permit process length and overhead.

b. Relaxed environmental windows.

c. Improved resource agency coordination and cooperation.

d. Reduced endangered species monitoring.

Mission and Efficiency Enhancement

These are economic benefits that actually or potentially occur as a direct result of the use or influence of one or more DRP products versus alternatives involving fixed-cost government physical plant.

Indirect Costs

Indirect cost benefits are economic benefits that are a higher-order consequence of the use or influence of one or more DRP products. Two examples are:

a. Quantified worth of uninterrupted commercial operations.

b. Improved public relations or opinion.

5 Task 3: Database Development

CEWRC Database

During the data acquisition, analysis, and synthesis tasks of this study, much use was made of the Water Resources Support Center-Navigation Data Center's (CEWRC) Dredging Statistics Program database. There were two major areas where statistical information from the CEWRC database was used:

a. Project-level specifics. Although the analysis looked at benefits estimation from fiscal year 1987, a fiscal year 1990 through 1992 window was adopted as the primary focus of District and Division recurring operations and maintenance project candidates for DRP product use. The individual benefit calculations produced were based on District project completion report data augmented, where needed, by information from the CEWRC database. Some items pulled from the database, along with their uses, were:

(1) Work type (new work or maintenance). An important distinction in the final results of this report was the separation of operations and maintenance from new work or other one-time-only benefits.

(2) Primary dredge type and placement method. Several hopper dredge or tug and scow cycle times were calculated, in part, with this information.

(3) Estimated start and end dates. Benefit calculations that were derived from project durations, most notably those involving survey crew mobilization and hopper rental projects, were obtained in part from this information.

(4) Equivalent cubic yards dredged. Some draghead efficiency and nearshore haul distance benefits were obtained in part from this information.

(5) Total estimated cost. Where unit cost was not available, it was estimated from this information and the equivalent cubic yard data.

b. *Overall workload.* While the detailed information from the CEWRC database was important, so was the overview of an individual District's workload that the database provided. An immediate understanding or "feel" of a District's scope of operations, such as what percent of open-water or on-beach disposal occurred annually, was instrumental in preliminary identification of which DRP products would pertain to which projects, if any. As a result, the subsequent District data collection meetings were more detailed and fruitful.

Benefits Database

The task of summarizing the actual calculated economic benefits of the DRP benefits analysis was accomplished by creating a two-dimensional and two-part and District-specific database that listed all quantified benefits by category and referenced them to technical area, product, and project.

This database was populated after the data collection, analysis, and synthesis tasks were completed. From the outset, the category of a certain calculated benefit was determined by identifying whether the benefit resulted from an O&M, new work, or government physical plant project or whether litigation, regulation, or environmental issues were involved. After deciding the category, individual benefits were annualized to FY 1994 values, rounded to the nearest thousand dollars, and entered into the database corresponding to product and technical area.

In order to simplify benefit data entry and accountability, product and work unit designations were modified and condensed into more compact entities. Modifications mirrored the actual benefits calculations, in that each entry of the modified product list corresponded to one or more actual calculated benefits.

Technical Area 1

- Sediment fate and transport numerical models.
- Sediment erodability characteristics.
- Plume monitoring system.

Technical Area 2

- Fluid mud constant density determination.
- Acoustic profiling methods.

- Sediment dredgeability determination.
- Rock dredgeability determination.

Technical Area 3

- Draghead modifications.
- Eductor/pump dredging methodology.
- Hopper bin monitoring efficiency.
- Single-point mooring buoy concept.
- Water injection dredging methodology.

Technical Area 4

- Vertical motion measurement system.
- Automated real-time tidal elevation system.
- Production meter systems.
- Silent Inspector system.

Technical Area 5

- Dredge plant manuals.
- Berm placement methodology.
- Capping methodology.
- Site management methodology.
- Technology transfer.

Additional information was provided with each calculated benefit to give a complete picture of that benefit's influence. This information included the fiscal year, whether the benefit was actual or potential, and whether the benefit recurred or was one-time. The actual calculation, along with its annualized amount and rounded amount, was included, as was the corresponding calculation sheet number for reference purposes. A complete listing of all sections of the DRPBA database is included in a separate appendix.

Lastly, many items that were identified as possible benefits during District discussions were not quantified, either because the projects were in an early planning stage or because District staff did not feel comfortable with an accurate estimate, due to a lack of verifiable results. These benefits are all noted in the database with the word "possible" in their category column. Chapter 8 of this report provides a detailed discussion of each.

6 Task 4: Data Collection and Organization

Data Collection

The data collection procedure focused on field visits and interviews with personnel directly involved with dredging operations. Meeting attendance was not consistent, but generally included branch chiefs from the navigation, construction, operations, regulatory, or geotechnical sections, depending on the District organizational structure. During these meetings, a general overview of the District's dredging schedule was conducted, followed by a comprehensive applicability review for all DRP products per District project. Actual or potential project uses identified during the field visits were either quantified into tangible values or highlighted as possible future benefits, pending further planning or added information. Other benefits were quantified from follow-up phone calls.

Specific anticipated or projected benefits may fail to materialize exactly as forecast in this report. However, it is likely that others have arisen or will arise to compensate for this "loss." This report should be viewed as one snapshot of a continuously evolving process. Although a series of such snapshots will differ in detail, the overall process will likely look the same.

Quantification

During the quantification process, any assumptions made were based on input from either WES staff, District personnel, or the benefits analysis team. Additionally, since the magnitude of each quantified benefit may not be 100-percent attributable to the DRP, a percentage of credit was assigned based on WES or District staff input. As an example, the benefits calculated from potential use of the Differential Global Positioning System were assigned a 50-percent credit attributable to the DRP. In the opinion of some District staff, these benefits would not be possible without the work done by the DRP. However, much research has also been done outside of the DRP, and assigning 50-percent credit was meant to recognize these influences. As another

example, the Los Angeles District's nearshore berm placement project benefits were assigned a 20-percent credit to account for the District's own substantial input. Examples of benefits produced with 100-percent-attributable DRP credit include those from use of the modified draghead at Aransas Pass and York Spit, and use of ARTTES on the Charleston Harbor Entrance Channel project. The flowchart shown in Figure 2 illustrates the approach to benefit identification and quantification used in this study.

Organization

Annual continuous benefits

Annual expected continuously recurring O&M benefits from use of DRP products are listed in Table 1 (annualized to FY January 1994 dollars). These benefits are raw numbers that have not been subjected to any analysis, including incorporation of uncertainty, influence of the DRP, and risk associated with each number. They represent potential savings that may result from using each DRP product. Calculation sheets and annualization processes for each of the benefits are given in a separate appendix, which also contains a table defining the acronyms used for each District name.

Table 2 is a list of non-O&M direct continuous benefits[1] that were identified during District field data collection. Although continuous non-O&M direct benefits are few in number, each one of these three entries is an excellent example of the DRP's influence on contemporary dredging problems.

One-time benefits

Raw costs for one-time benefits are shown in Table 3. These one-time benefits[1] were realized on both new work and O&M dredging projects. Although these benefits occurred only once in the time period covered by this analysis, there is no reason to believe that similar one-time benefits would not happen in following years.

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[1] Annualized to FY January 1994 dollars.

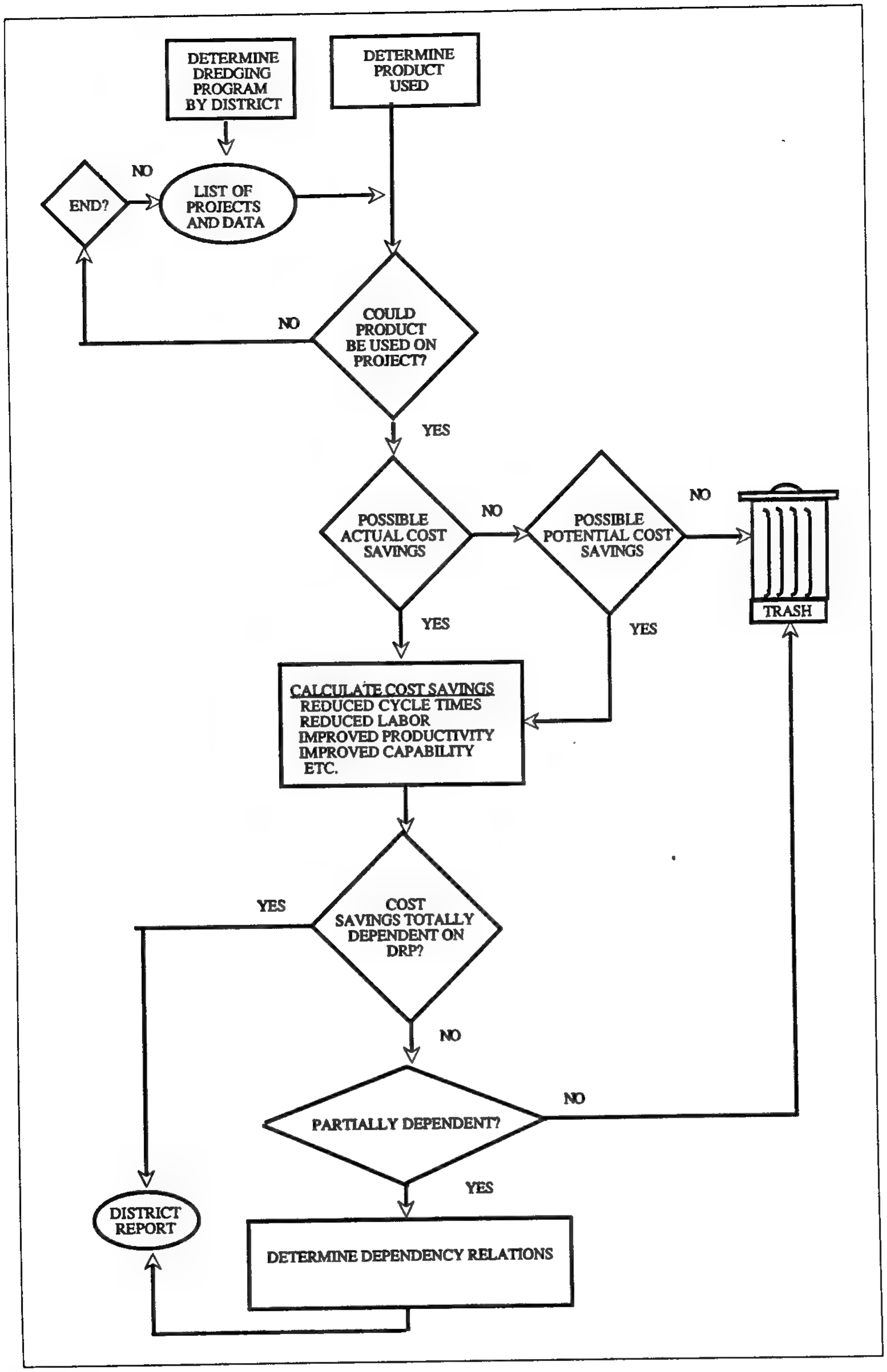

Figure 2. Benefit identification and quantification approach

Table 1
Annual Expected Continuously Recurring O&M Benefits, in 1994 Dollars

District	Project	Benefit Type	FY94 Benefit	FREQ.(YRS)[1]
LMK	Red River	O+M Direct	$60,000	1
	Ouachita/Black Rivers	O+M Direct	$600,000	1
LMN	WHEELER bin load accuracy	Efficiency	$222,000	1
	WHEELER data logging automation	Efficiency	$6,000	1
	WHEELER SWP DGPS	Efficiency	$111,000	1
	WHEELER Hopper EM	Efficiency	$6,000	1
	WHEELER/MCFARLAND bin meas	Efficiency	$362,000	1
	Contract overflow monitoring	O+M Direct	$500,000	1
	MRGO DGPS	O+M Direct	$50,000	1
	Berm placement projects	O+M Direct	$417,000	3
NAN	MCFARLAND bin measure	Efficiency	$111,000	1
	Jones Inlet	O+M Direct	$95,000	3
	East Rockaway Inlet	O+M Direct	$73,000	2
	East Rockaway Inlet	O+M Direct	$71,000	2
	Jamaica Bay/Rockaway Inlet	O+M Direct	$89,000	2
	Jamaica Bay/Rockaway Inlet	O+M Direct	$26,000	2
	Mud Dump Site monitoring	O+M Direct	$70,000	1
	Mud Dump Site life	O+M Direct	$4,413,000	1
NAO	NASA Wallops Island	O+M Direct	$216,000	1
	Tylers Beach James River	O+M Direct	$92,000	5
	York Spit II	O+M Direct	$5,000	5
	Contract hopper projects	O+M Direct	$22,000	1
NAP	MCFARLAND bin measure	Efficiency	$45,000	1
	Indian River Inlet	O+M Direct	$158,000	1
NCB	Sandusky River	O+M Direct	$19,000	1
	Cayuhoga River Bratenhall	O+M Direct	$15,000	1
	Survey/positioning setup	O+M Direct	$64,000	1
NCE	Duluth Harbor	O+M Direct	$28,000	1
	Alpena Harbor	O+M Direct	$23,000	10

(Sheet 1 of 3)

[1] Cycle refers to the frequency recurrence interval of each project. Each project interval is used to calculate the annual FY 1994 project benefit.

Table 1 (Continued)

District	Project	Benefit Type	FY94 Benefit	FREQ.(YRS)[1]
NCE	Rouge River	O+M Direct	$96,000	3
	Survey/positioning setup	O+M Direct	$105,000	1
NCR	River pipeline discharge	O+M Direct	$100,000	1
NED	MCFARLAND bin measure	Efficiency	$16,000	1
NPP	ESSAYONS/YAQUINA bin measure	Efficiency	$331,000	1
	MCR draghead	O+M Direct	$45,000	1
	Shore transponder	O+M Direct	$20,000	1
	Survey/positioning setup	O+M Direct	$70,000	1
	Contract administration	O+M Direct	$13,000	1
NPS	ESSAYONS/YAQUINA bin measure	Efficiency	$44,000	1
	Cedar River	Non O+M Direct	$6,000	1
	Grays Harbor Half Moon Bay	O+M Direct	$69,000	1
	Grays Harbor South Beach	O+M Direct	$200,000	1
	Grays Harbor South Beach	O+M Direct	$60,000	5
	Entrance and bar channels	O+M Direct	$35,000	1
	Contractor monitoring	O+M Direct	$13,000	1
SAC	Charleston Harbor Entrance	O+M Direct	$27,000	2
SAJ	Miami Harbor	O+M Direct	$60,000	10
	Tampa Harbor Bar	O+M Direct	$47,000	3
	Survey/positioning setup	O+M Direct	$106,000	1
	Fernandina sea turtle	Regulatory	$188,000	1
SAM	Mobile Harbor/Bay	O+M Direct	$144,000	1
	Panama City Harbor	O+M Direct	$205,000	1
	Mobile Harbor	O+M Direct	$215,000	3
	Gulfport Harbor	O+M Direct	$322,000	3
	Mobile Bay	O+M Direct	$429,000	1
	Contract hopper projects	O+M Direct	$322,000	1
SAS	Brunswick Entrance	Claim avoidance	$113,000	1
	Brunswick Bar Jekyll Island	O+M Direct	$413,000	1
	Savannah Bar Tybee Island	O+M Direct	$362,000	1
	Savannah River/Harbor/Channel	O+M Direct	$449,000	1
	Savannah Harbor sea turtle	Regulatory	$170,000	1

(Sheet 2 of 3)

Table 1 (Concluded)

District	Project	Benefit Type	FY94 Benefit	FREQ.(YRS)[1]
SAS	Brunswick Harbor sea turtle	Regulatory	$170,000	1
	Kings Bay sea turtle	Regulatory	$170,000	1
SAW	Sunny Point Military Ocean Terminal	O+M Direct	$540,000	3
	Survey/positioning setup	O+M Direct	$154,000	1
SPL	San Diego Harbor Silver Strand	O+M Direct	$14,000	10
	Ventura Harbor	O+M Direct	$30,000	1
	Morro Bay	O+M Direct	$55,000	3
SPN	Contract claim	Claim avoidance	$193,000	1
	ESSAYONS/YAQUINA bin measure	Efficiency	$91,000	1
	Humboldt Harbor	O+M Direct	$192,000	1
	Humboldt Bay	O+M Direct	$34,000	2
	Survey/positioning setup	O+M Direct	$18,000	1
	Richmond Harbor	O+M Direct	$41,000	1
	Alcatraz Site Life	O+M Direct	$1,602,000	1
	Hopper efficiency	O+M Direct	$328,000	1
	Contract administration	O+M Direct	$7,000	1
	Contract contingency fund	O+M Direct	$55,000	1
SWG	Aransas Pass	Efficiency	$23,000	4
	WHEELER bin measure	Efficiency	$109,000	1
	Sabine Pass	O+M Direct	$708,000	3
	Trinity River	O+M Direct	$150,000	2
	Houston Ship Channel	O+M Direct	$558,000	5
	Matagorda Ship Channel	O+M Direct	$231,000	5
	Survey/positioning set up	O+M Direct	$162,000	1

(Sheet 3 of 3)

Table 2
Non-O&M Direct Continuous Benefits, in 1994 Dollars

District	Project	Benefit Type	FY94 Benefit	FREQ.(YRS)
NAN	Mud Dump Site	Non O+M Direct	$4,413,000	Cont.
SPN	Alcatraz Site	Non O+M Direct	$3,246,000	Cont.
NPS	Cedar River	Non O+M Direct	$6,000	Cont.

Table 3
One-Time Benefits, in 1994 Dollars

District	Project	Benefit Type	FY94 Benefit
LMN	Heave measurement	Non O+M Direct	$15,000
NAN	Replacement Ocean Disposal Site	O+M Direct	$300,000
	New York Bay capping	Indirect	$5,800,000
	New York Bay capping	O+M Direct	$916,000
	Arthur Kill deepening	Non O+M Direct	$132,000
	Heave measurement	Non O+M Direct	$15,000
NAO	Norfolk Harbor	Non O+M Direct	$42,000
	York Spit	Claim avoidance	$2,007,000
	Thimble Shoal	Non O+M Direct	$115,000
	York Spit	Non O+M Direct	$157,000
	York Spit II	Non O+M Direct	$384,000
	Cape Henry	Non O+M Direct	$99,000
	Heave measurement	Non O+M Direct	$15,000
	Wolf Trap Alternate Site	O+M Direct	$44,000
NAP	Delaware River Deepening	Non O+M Direct	$115,000
	Delaware Coast Beach Fill	Non O+M Direct	$161,000
	Townsons Inlet	Non O+M Direct	$50,000
	Delaware Bay Beach Fill	Non O+M Direct	$75,000
	Heave measurement	Non O+M Direct	$15,000
NCB	Heave measurement	Non O+M Direct	$15,000
NCE	Duluth Harbor	Claim Avoidance	$72,000
NED	Boston Harbor Deepening	Non O+M Direct	$40,000
	Heave measurement	Non O+M Direct	$15,000
NPA	Anchorage Harbor	Claim avoidance	$973,000
NPP	Heave measurement	Non O+M Direct	$15,000
NPS	Bellingham Bay PSDDA	O+M Direct	$32,000
	Shemya AFB	Non O+M Direct	$242,000
	Shore protection structures	Non O+M Direct	$81,000
	Denny Way	Non O+M Direct	$463,000
	Grays Harbor draghead	Non O+M Direct	$96,000
	Heave measurement	Non O+M Direct	$15,000

(Continued)

Table 3 (Concluded)			
District	**Project**	**Benefit Type**	**FY94 Benefit**
ORL	Contractor rated performance	O+M Direct	$473,000
SAC	Charleston Harbor Folly Island	O+M Direct	$54,000
	Charleston Harbor deepening	Non O+M Direct	$46,000
	Charleston Harbor deepening	Regulatory	$4,601,000
	Heave measurement	Non O+M Direct	$15,000
SAJ	Miami Site redesignation	Non O+M Direct	$1,150,000
	Tampa Site redesignation	Non O+M Direct	$1,150,000
	Fernandina Site redesignation	Non O+M Direct	$1,150,000
	Canaveral Site redesignation	Non O+M Direct	$1,150,000
	Heave measurement	NON O+M Direct	$15,000
SAM	Mobile Outer Mound	O+M Direct	$4,356,000
	Pensacola Homeport deepening	Non O+M Direct	$166,000
	Panama City Harbor	Non O+M Direct	$2,483,000
	Heave measurement	Non O+M Direct	$15,000
	Gulfport Harbor deepening	Claim avoidance	$1,234,000
	Dredge pump capability	Claim avoidance	$536,000
	Dike construction	Non O+M Direct	$1,073,000
	Panama City Harbor deepening	Non O+M Direct	$200,000
SAW	Heave measurement	Non O+M Direct	$15,000
SAS	Heave measurement	Non O+M Direct	$15,000
SPL	Marina del Rey	Non O+M Direct	$758,000
	Santa Barbara Harbor	Non O+M Direct	$4,000
	Heave measurement	Non O+M Direct	$15,000
SPN	Naval Air Station Alameda	Non O+M Direct	$234,000
	Heave measurement	Non O+M Direct	$15,000
	Oakland/Richmond alignment	Claim avoidance	$38,000
	Oakland/Richmond alignment	Claim avoidance	$54,000
	Oakland Harbor	Non O+M Direct	$192,000
	Oakland Harbor	Non O+M Direct	$69,000
SWG	Galveston Beach Fill	Non O+M Direct	$22,000
	Freeport Harbor	Non O+M Direct	$269,000
	Heave measurement	Non O+M Direct	$15,000

7 Task 5: Data Calculation, Quantification, and Organization

Annual Continuous Benefits

Calculation of raw data

Annual continuous cost savings and one-time cost savings from the use of DRP products were estimated using project-specific assumptions that resulted from the collective judgement of the authors, District personnel, and DRP investigators. These assumptions are stated on the calculation sheets in a separate appendix. There are several questions that immediately arise when one looks at the data. Consider Figure 3, which represents annual continuous benefits, by District.

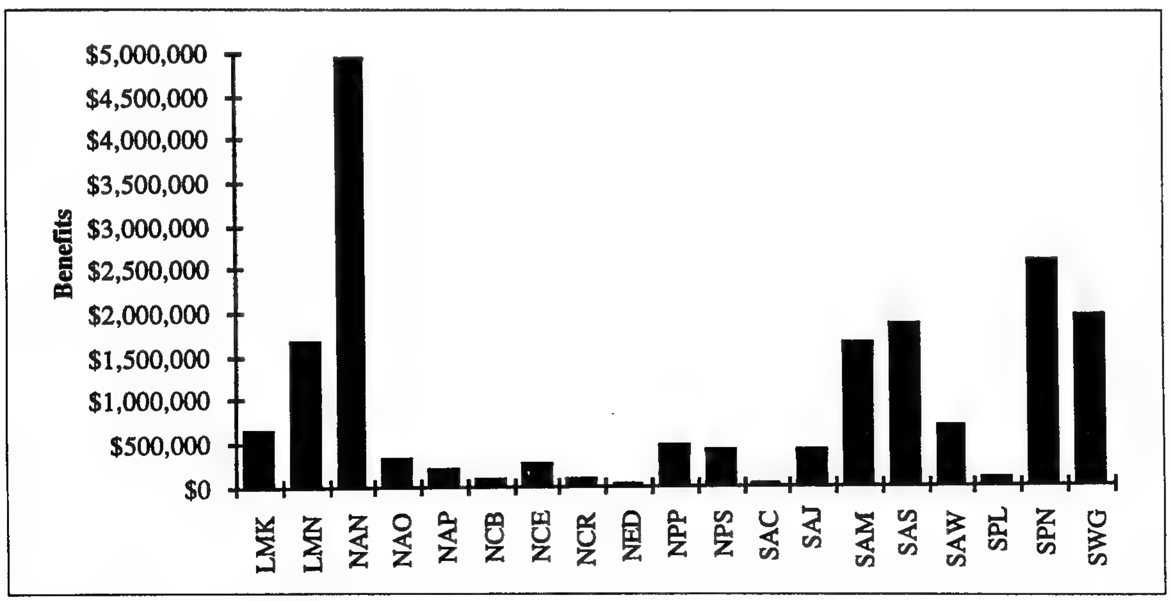

Figure 3. Total annual continuous benefits, by District (raw data), in 1994 dollars

Largest benefits. By far the largest annual benefits are in the following seven Districts:

New York	$4,989,000
San Francisco	$2,561,000
Galveston	$1,941,000
Savannah	$1,847,000
New Orleans	$1,674,000
Mobile	$1,637,000
Wilmington	$694,000
Total	$15,343,000

These seven Districts accounted for 82 percent of the O&M benefits calculated. But is this correct? Is there an immediate bias in the data? Consider each District, in turn, as shown in Figure 4 (sorted from high values to low).

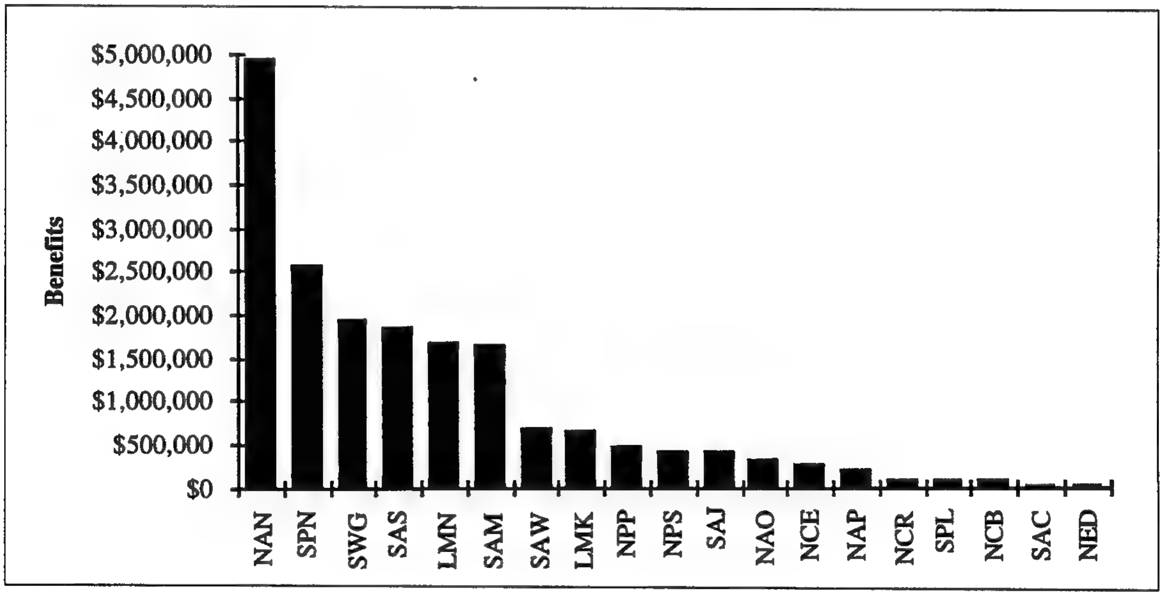

Figure 4. Total annual continuous benefits, by District (raw data), in 1994 dollars

New York District (NAN). Estimated annual O&M economic benefits are $4,989,000. Nearly 89 percent of these benefits come about because the Mud Dump open-ocean dump site has been allowed to remain open. The District estimates it would cost an average of $8.2 million annually to move to a new ocean-dumping site, assuming that one could be designated. Therefore, extending the life of the Mud Dump should save this amount. In this study, a credit of half this amount has been considered as DRP-attributable annual O&M savings. While the amount of benefits seems large, the value of the

Mud Dump site to the Harbor of New York cannot be overstated. There are virtually no upland disposal sites available for even slightly contaminated dredged material. NAN has aggressively sought help from the DRP in maintaining the Mud Dump site through capping techniques, site-management, and sediment transport models. In addition, the Silent Inspector will result in fuller use of remaining site capacity, thereby further prolonging site life.

San Francisco District (SPN). SPN has nearly $2.6 million in estimated annual O&M benefits. The bulk of these benefits (63 percent) come from use of SPN's version of the Silent Inspector in monitoring the accuracy and volume of dredged material dumping at the Alcatraz site. Like the Mud Dump site in New York, Alcatraz is vital to the health of the San Francisco Bay port facilities. In addition, it is politically and environmentally sensitive with strong forces seeking its closure. Without Alcatraz, the cost of maintenance dredging in San Francisco would increase tenfold.

Galveston District (SWG). The Galveston District performs an extremely large volume of dredging, and has aggressively sought DRP prototype and demonstration projects. SWG has assisted PI's and project managers in the DRP. By doing so, SWG has proactively caused a technology transfer paradigm. By being able to efficiently measure the depth and density of fluid mud in Sabine Pass, SWG could reduce the annual amount of dredging substantially. Increased productivity through an improved draghead design might also save considerable funds in dredging Aransas Pass. Water injection dredging could produce benefits on the Trinity River, Houston Ship Channel, and Matagorda Ship Channel.

Savannah District (SAS). The Savannah District has sought prototype DRP projects and as such they have proactively affected considerable technology transfer. With major environmental limitations on SAS dredging programs, SAS is planning to make use of a new draghead design to protect sea turtles, thereby extending SAS dredging windows. SAS is also considering near-shore berm placement to reduce dredging cycle times and site-management strategies to identify alternate disposal options.

Mobile District (SAM). Mobile has, since the days of the earlier Dredged Material Research Program, aggressively and innovatively sought research prototype projects. They are also one of the coastal Districts nearest to WES, resulting in some close interactions with DRP researchers. It was not unexpected that they would be one of the first Districts to show substantial benefits from the use of DRP products. Some of the areas in which SAM could reap benefits include manual hopper bin load monitoring and reduced operational costs through the use of water injection dredging and the acoustic profiler.

New Orleans District (LMN). LMN executes the largest O&M dredging program in the Corps of Engineers, averaging over $44 million annually (Figure 5) and accounting for 17 percent of the entire Corps maintenance dredging budget. LMN is in the very early stages of using DRP products, and some District staff feel their annual O&M savings are considerably understated. Some of the areas in which the District could benefit include increasing the efficiency of hopper rental contracts through bin monitoring technology and reducing disposal costs with nearshore disposal methodology.

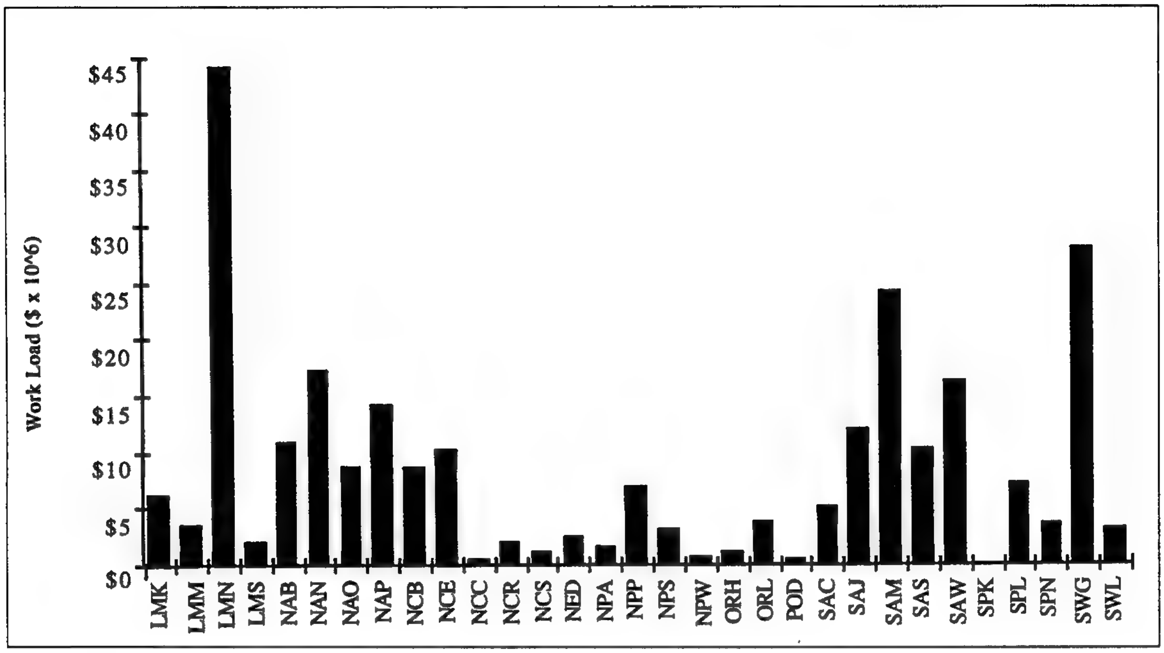

Figure 5. Average annual O&M workload, in 1994 dollars

Wilmington District (SPW). SPW has been a leading force in the development and implementation of the Differential Global Positioning System. District personnel see potential benefits from reduced positioning system setup times for hydrographic survey operations. Accurate measurement of fluid mud density at Sunny Point Military Ocean Terminal (MOT) could reduce that project's scope.

Notable benefits. Several other Districts also produced notable continuous benefits:

a. Vicksburg District (LMK). Estimated annual O&M benefits to LMK are centered solely on the use of submersible pumps, which have allowed contractors to optimize their resources on both short-notice and scheduled dredging projects.

b. Los Angeles District (SPL). SPL has gained O&M benefits from nearshore disposal methodology. The District has been a front-runner in identifying potential projects, traditionally done by hydraulic physical

plant, that would be suitable for medium hopper dredging and near-shore placement. One of the earliest field tests of this procedure was conducted on the San Diego Entrance Bar, and more work is being scheduled at Morro Bay and Ventura Harbor. Allowing hopper contractors into the bidding process has stimulated competition and, subsequently, project bids more attractive to the government have resulted.

c. *Norfolk District (NAO).* The small magnitude of NOA's benefits relative to other Districts clouds the fact that the District has diverse and unique needs for DRP products. District staff have been actively pursuing solutions to some of their problems through DRP products. A prominent example is alternative disposal costs avoided through use of the PLUMES Monitoring System on the Tyler's Beach Project. On this project, continued in-river disposal under specific environmental scrutiny was allowed. The District is also planning on reducing the manual monitoring of hopper bin loading as well as reducing design time for the Wolf Trap Alternate Site. Some haul distance benefits were realized, in part due to the influence of nearshore disposal technology at Chincoteague Inlet.

d. *Seattle District (NPS).* Like NAO, the low magnitude of NPS's benefits relative to others masks the fact that their benefits are among the most robust. Seattle has made the most impressive use of the numerical fate and transport models in applications such as the Puget Sound Dredged Material Disposal Analysis. A notable non-Federal example that also applies recurrently to similar O&M work is the Cedar River project, in which design and administration efforts associated with regulatory and/or legal scrutiny were reduced as a result of model usage. Both berm creation methodology and the single point mooring buoy are being planned for use at Grays Harbor. Their benefits will be realized in comparison to more costly hydraulic plant on-beach replenishment. Also, use of the differential global positioning system (DGPS) could produce a reduction in entrance bar dredged volumes.

e. *Jacksonville District (SAJ).* SAJ operates in an intense regulatory environment that has caused the District to look to DRP products for assistance. A notable area of impact centered on the Miami Harbor avoided site re-designation, which was attributable, in part, to the PLUMES Monitoring System. The District also hosted a DRP field test of the prototype modified heel-pad draghead, and District staff feel that the product, when perfected, could both increase protection of sea turtles on dredging projects like Fernandina and Canaveral Harbors and increase dredging production of the Tampa Harbor Entrance Bar material.

f. *Portland District (NPP).* NPP has actively sought DRP product assistance in coping with some of the problems encountered in its large and diverse dredging schedule. A field test of the Silent Inspector system

was conducted on the hopper dredge Essayons, demonstrating that the system was functional and that District personnel could streamline administrative procedures once the system is implemented. Also, the District is contemplating use of either the ARTTES or DGPS on both of its entrance bar projects to increase the accuracy of dredged volumes.

g. *Buffalo District (NCB).* A major part of the estimated annual O&M benefits to Buffalo District results from actual use of the berm placement methodology product. NCB has realized solid benefits from reduced disposal costs versus traditional alternatives on both the Cayuhoga and Sandusky River projects.

h. *Detroit District (NCE).* NCE can benefit from the influence of several DRP products. District personnel see benefits from potential berm placement in Lake Huron at Alpena Harbor as well as the modeling of open-water disposal in Lake Superior at Duluth Harbor. Also, accurate measurement of fluid mud density at Rouge River could reduce that project's scope.

i. *Rock Island District (NCR).* Annual O&M benefits to NCR could be gained with use of the numerical fate modeling product. The District staff feels that better monitoring of pipeline discharge could reduce regulatory pressures on riverine dredging projects.

j. *Charleston District (SAC).* Estimated annual O&M benefits to SAC are centered on use of the ARTTES product. The District has had success in allowing for more complete and efficient optimization of their hydrographic survey resources with ARTTES.

Forecast benefits. These direct benefit estimates were quantified as a result of field data collection interviews with Corps dredging personnel. All estimates contain some element of uncertainty, and estimates involving future research product benefits may have more than most. While the interview process was designed to be as accurate as possible, the information identified could still only represent the moment in time from which it was taken. The dynamic environment in which dredging projects occur lends itself to many changes or constraints imposed after the exact moment of identification (including budget, project scope, time, or resource) that could affect these estimates and create uncertainty. Therefore, to account for some of the uncertainty, a Monte Carlo simulation analysis was performed. The analysis developed values with a 90-percent certainty that the actual or potential benefits will exceed. In other words, the benefits developed in the simulation analysis have a 0.90 probability of being exceeded.

In order to perform a Monte Carlo analysis, an assumption was made that each benefit estimate would follow a Weibull distribution. This distribution was chosen because it has a finite lower bound and a boundless upper limit,

and can be skewed to the conservative side. The equation for the Weibull distribution is:

$$f(x) = \frac{\alpha x^{\alpha-1}}{\beta^{\alpha}} e^{-\left(\frac{x}{\beta}\right)^{\alpha}} \quad (1)$$

where

x = estimated benefits

α = shape factor

B = scale factor

An example of the distribution function is shown in Figure 6.

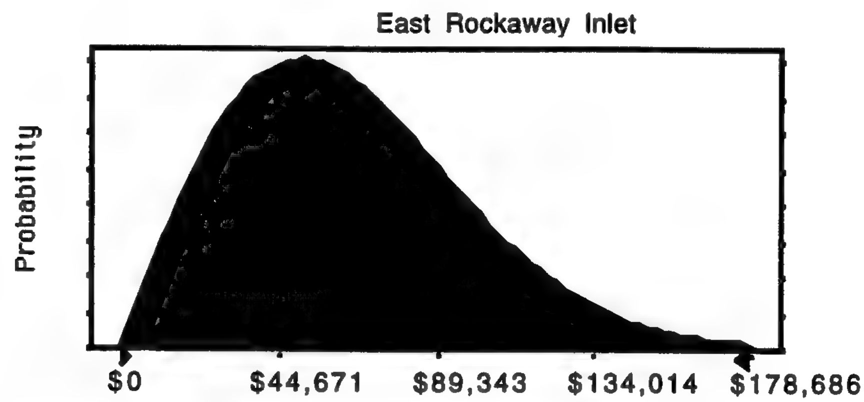

Figure 6. Example of Weibull distribution of O&M benefits for the East Rockaway Inlet project

A Monte Carlo simulation sums the individual project benefits a large number of times. At each calculation of a project benefit, a random number from a uniform distribution is selected. That random number is the probability that the benefits will be less than or equal to a certain amount, say x dollars. The value of x comes from the equation:

$$x = -\beta[\ln(1 - F(x))]^{\frac{1}{\alpha}} \quad (2)$$

which is the inverse of the cumulative Weibull distribution. As each simulation is completed, its value is stored and tallied into a relative frequency histogram, as shown in Figure 7.

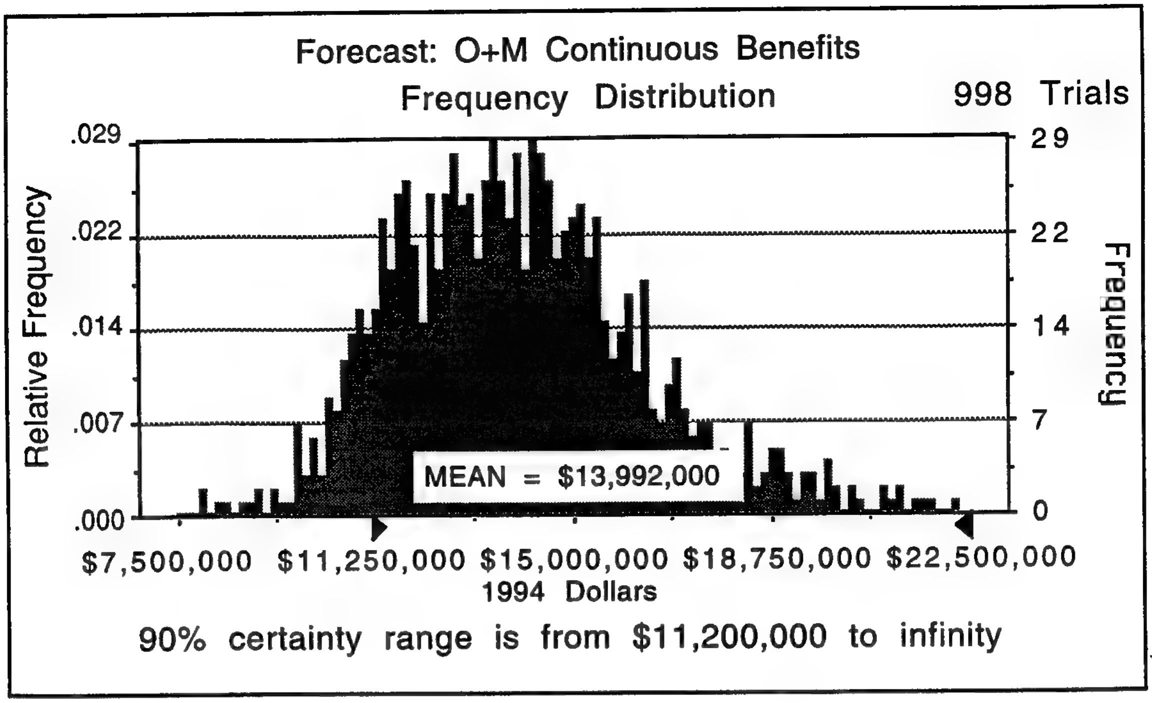

Figure 7. Simulation results of the total annual O&M benefits

O&M benefits. Based on simulation results, Figure 7 shows there is a 0.90 probability that annual O&M benefits from the use of DRP products will exceed $11,200,000 in 1994 dollars. Therefore, 5-year O&M benefits from the use of DRP products will probably exceed $64,700,000 in 1994 dollars, using the 7.25-percent OMB-specified discount rate.

Mean = $13,991,682
Standard deviation = $2,327,819
Coefficient of variation = 17%

Plant efficiency enhancement benefits. Based on simulation results, there is a 0.90 probability that annual Corps-owned dredge plant efficiency enhancement benefits from the use of DRP products will exceed $965,000 in 1994 dollars (Figure 8).

Mean = $1,292,476
Standard deviation = $255,232
Coefficient of variation = 20%

Regulatory benefits. Based on simulation results, Figure 9 shows probability that annual regulatory benefits from the use of DRP products will exceed $413,000 in 1994 dollars.

Mean = $620,017
Standard deviation = $161,147
Coefficient of variation = 26%

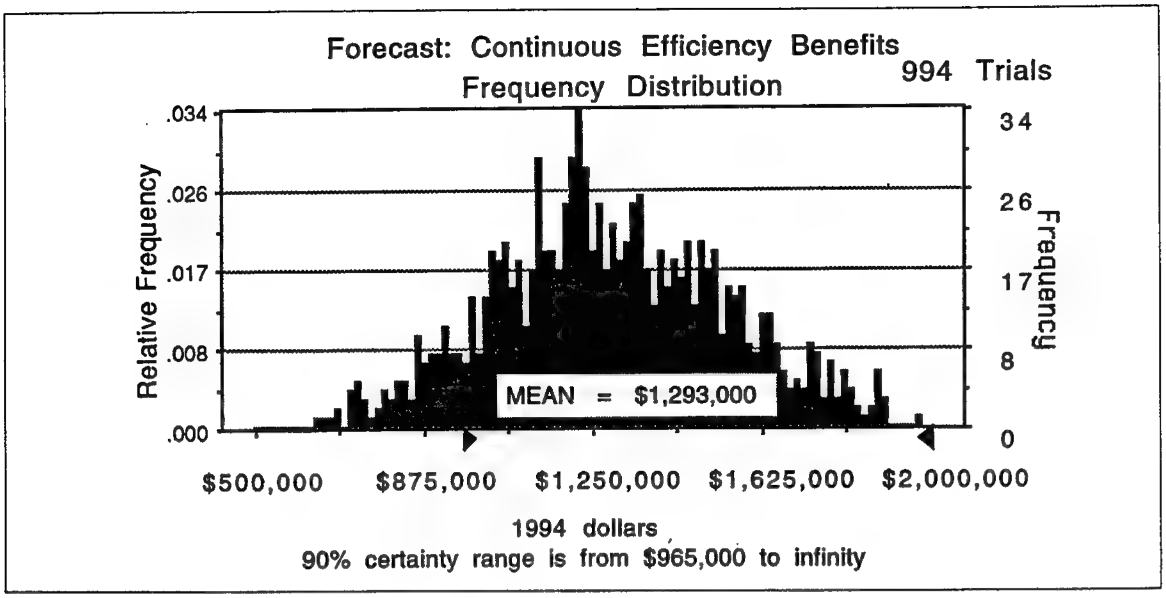

Figure 8. Simulation results of the continuous efficiency enhancement benefits

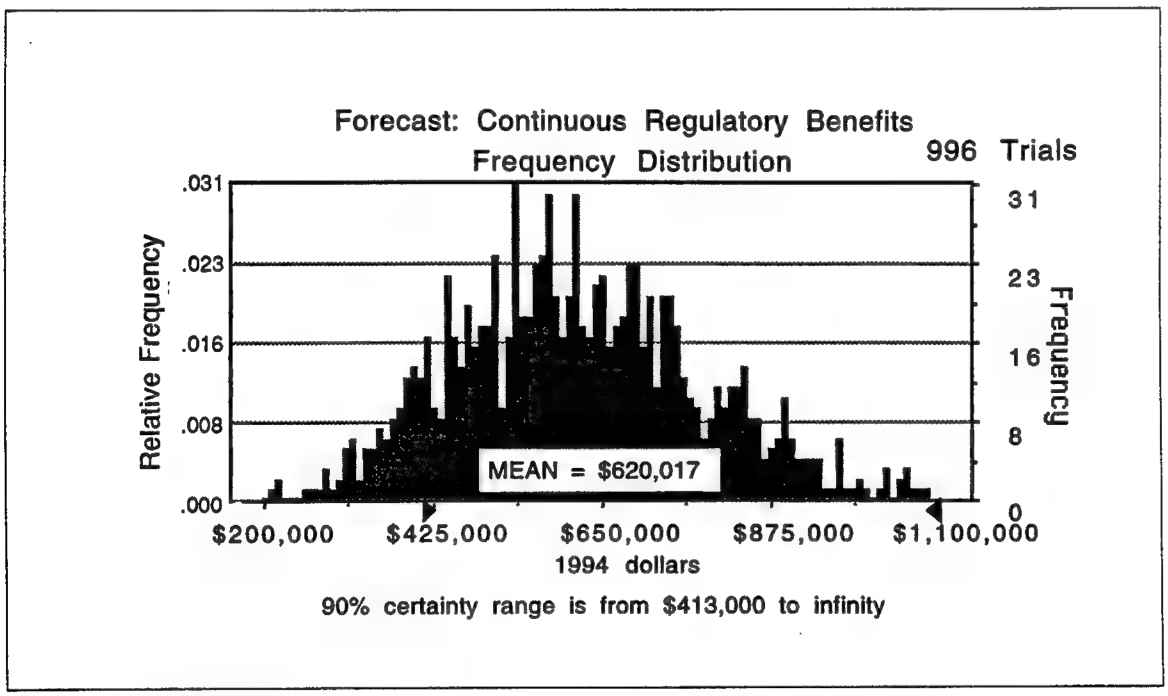

Figure 9. Simulation results of the continuous regulatory benefits

Claim avoidance benefits. Based on simulation results, Figure 10 shows there is a 0.90 probability that annual claim avoidance benefits from the use of DRP products will exceed $413,000 in 1994 dollars.

Mean = $270,867
Standard deviation = $ 96,089
Coefficient of variation = 36%

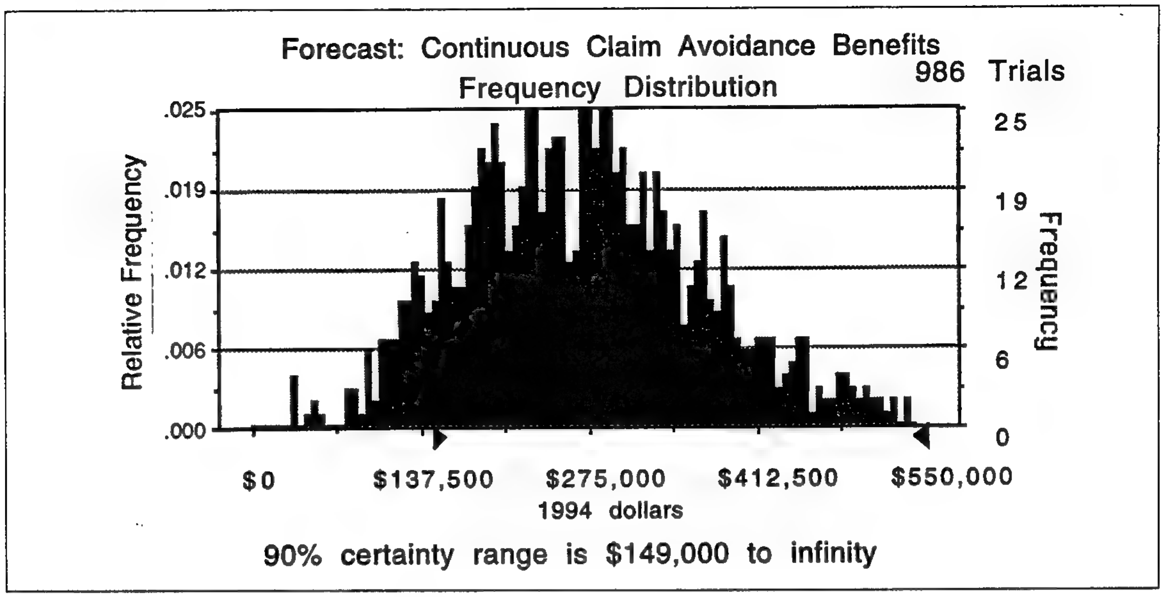

Figure 10. Simulation results of the continuous claim avoidance benefits

Non-O&M benefits. Based on simulation results, there is a 0.90 probability that annual non-O&M benefits from the use of DRP products will exceed $4,677,000 in 1994 dollars (Figure 11).

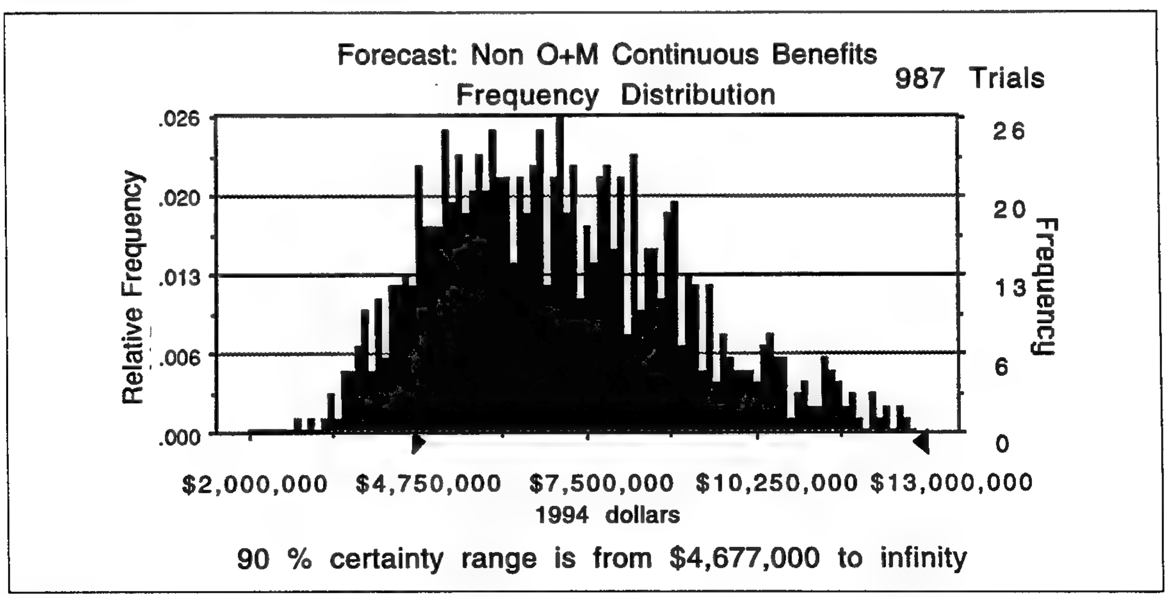

Figure 11. Simulation results of the continuous non-O&M benefits

Mean = \$7,059,841
Standard deviation = \$1,959,159
Coefficient of variation = 28%

Summary of continuous benefits

Table 4 is a summary of all quantified continuous benefits (90-percent assurance estimates). These project benefits were annualized into 1994 dollars. The 5-year savings should exceed \$100,586,000.

Table 4
Annual Continuous Benefits, in 1994 Dollars, Forecast Using Monte Carlo Simulation

Category	Figure No.	90% Value	Mean	Standard Deviation	Coeff. of Variation
O&M benefits	7	11,200,000	13,991,682	2,327,819	17%
Corps-owned plant efficiency benefits	8	965,000	1,292,476	255,232	20%
Regulatory benefits	9	413,000	620,017	161,147	26%
Claim avoidance benefits	10	149,000	270,867	96,089	36%
Non O&M benefits	11	4,677,000	7,059,841	1,959,159	28%
Total		17,404,000	23,234,883	4,799,446	

One-Time Benefits Data

As stated earlier, the primary goal of the DRP Benefits Analysis study was to gauge the effect of dredging research and development on the Corps-wide O&M program. However, while conducting the District field data collection visits, it became apparent to the benefits analysis team that noncontinuous projects were affected equally as much, if not more so, on a project-by-project basis. Significant benefits were quantified for both non-Federal and Federal new work and O&M projects. These benefits were not continuous, unlike the majority of their O&M counterparts; that is, they were one-time occurrences on projects with no dredging cycle.

Attempting to estimate future benefits for one-time projects presents difficulties. Since there is no repeatability within each respective District, there is no way to expect any effect other than the one-time occurrence within the District.

However, if a global rather than local view is considered, then one-time benefits projection could be logically justified. A global view of DRP research attributes the end result benefits of that research to the national Corps dredging program. A local view attributes the end results to the individual Districts. Benefits quantified for continuous O&M projects were viewed locally, attributed to each District, and their collective influence was summed and transferred to the Corps as a whole.

The same method would not be correct for quantifying one-time benefits, since no District-level repeatability exists. What does exist, however, is global repeatability. For instance, a certain District may have scheduled a new work project in a certain year. This project may use DRP technology, from which benefits could be produced. The project would not occur within the District again at a regular interval. Several of the other 30 or so dredging Districts, however, could have new work projects ongoing during the times that any one District does not. From a global Corps-wide perspective, all of these new work projects could be collectively considered as producing continuous benefits. These benefits could then be analyzed and simulated as such for the entire Corps dredging program. (Note: The calculation of raw data and the synthesis and analysis of the one-time benefits are presented for each of the various categories of benefits. This organization was considered more appropriate for the Corps-wide approach.)

O&M Benefits

One assumes that there will continually be one-time O&M projects within each District. Capping by the New York District was for a one-time disposal of some contaminated dredged sediment. It can further be assumed that there will be other contaminated sediment dredged in the future, but timing and amounts are uncertain. There is a potential use for the program management product on the upper Chesapeake Bay Wolf Trap disposal site. The site will be used for future York Spit deepening and maintenance work. There is no set disposal concept, and regulatory agencies are making suggestions for mound creation. The budget for surveys and engineering involved with layout and design of material placement is $110,000. The District staff estimated that the PC-based predictive fate and placement tools provided through the DRP would produce a 40-percent reduction in overall field and office effort. These projects and the others shown in the following table are valid O&M benefits derived from the DRP. They are difficult to annualize and will be analyzed separate and apart from the O&M maintenance benefits expected to occur each year. Table 5 lists the one-time O&M benefits that were calculated (raw data); Figure 12 shows the data sorted by District. Note that the Charleston Harbor Deepening benefits were actually regulatory. They have been included in the O&M one-time benefits for ease of reading.

Table 5
One-Time O&M Benefits (Raw Data)

Product	District	Project	Benefit
Fate models	NAN	Replacement ocean disposal site	$300,000
Capping	NAN	New York Bay capping	$916,000
Site management	NAO	Wolf Trap alternate site	$44,000
Fate models	NPS	Bellingham Bay PSDDA	$32,000
Production meter	ORL	Contractor rated performance	$473,000
Berm placement	SAC	Charleston Harbor Folly Island	$54,000
Berm placement	SAM	Mobile Outer Mound	$4,356,000
Draghead	SAC	Charleston Harbor deepening	$4,601,000
Total			$10,776,000

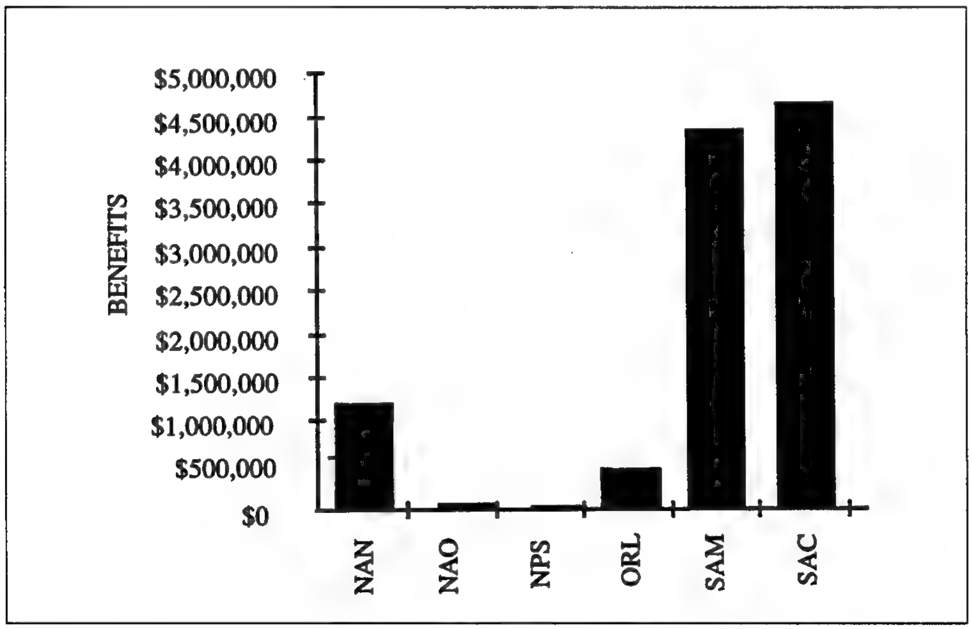

Figure 12. One-time O&M benefits sorted by District (raw data)

There is a 90-percent assurance that one-time O&M benefits calculated during this study period were at least $5,716,667 in 1994 dollars (Figure 13).

Mean = $9,364,854
Standard deviation = $2,980,434
Coefficient of variation = 32%

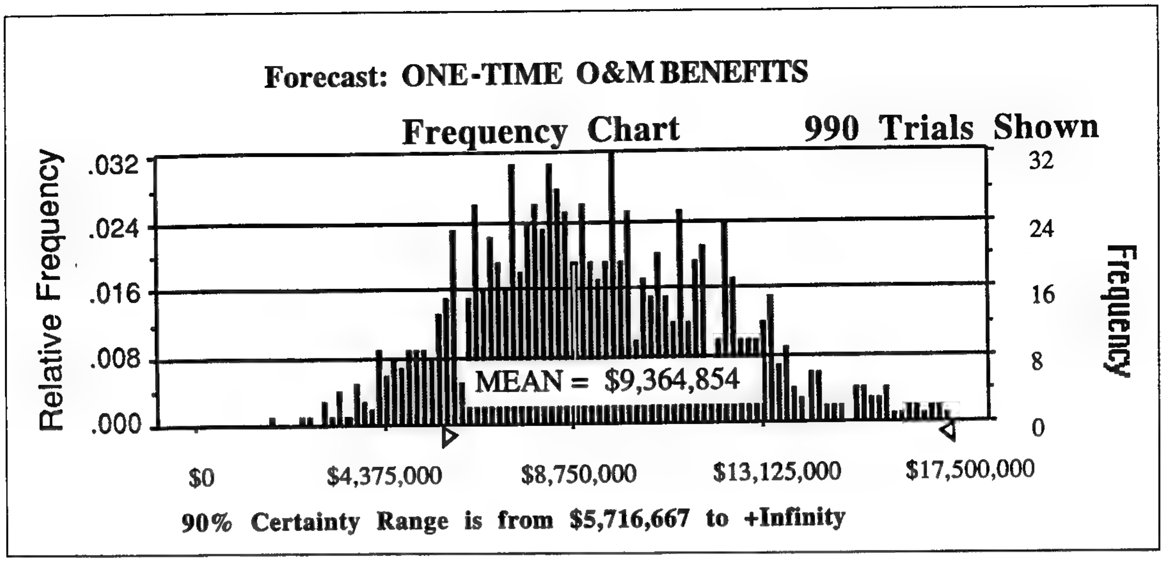

Figure 13. Simulation results for one-time O&M direct benefits

Claim Avoidance Benefits

Benefits associated with litigation or contract claim avoidances were the most difficult to quantify due to their volatile nature. For this reason, these benefits were the most under-represented of all the groups quantified. Great potential benefits exist with geotechnical-related Technical Area 2 products that could provide better (more precise) project data to contractors, thus avoiding or reducing the impact of differing site-condition claims. The projects listed in the following table could serve as examples of possible benefits that could also be derived from other Corps-wide projects involved in differing site claims. The San Francisco District had some problems with positioning on both the Oakland and Richmond Harbor projects. There is a potential use for the more accurate DGPS product in avoiding these problems in the future. Another special benefit that could have major application in other Districts involved the actual litigation expense avoidance brought on through transfer of DRP technology to defuse a dispute with a contractor in the Mobile District.

Table 6 is a listing of one-time claim avoidance benefits; Figure 14 presents them summed by District.

There is a 90-percent level of assurance that one-time benefits from avoiding claims on specific dredging projects will equal $2,913,333 or more in 1994 dollars (Figure 15).

Mean = $4,474,921
Standard deviation = $1,231,743
Coefficient of variation = 28%

Table 6 One-Time Claim Avoidance (raw data)			
Product	**District**	**Project**	**Benefit**
Dredgeability	NAO	York Spit	$2,007,000
Dredgeability	NCE	Duluth Harbor	$72,000
Dredgeability	NPA	Anchorage Harbor	$973,000
Acoustic profiler	SAM	Gulfport Harbor deepening	$1,234,000
Tech transfer	SAM	Dredge pump capability	$536,000
DGPS	SPN	Oakland/Richmond alignment	$38,000
DGPS	SPN	Oakland/Richmond alignment	$54,000
Total			$4,914,000

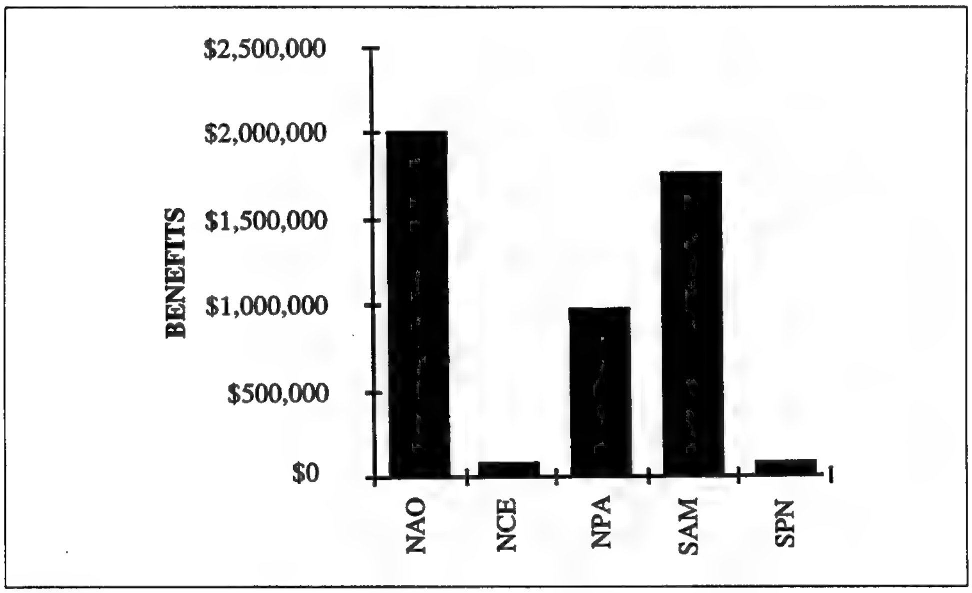

Figure 14. One-time claim avoidance benefits (raw data)

Non-O&M benefits

These benefits are associated with a broad group of sources. They include new work dredging projects and projects paid for by others such as port authorities or the Navy or Air Force Departments. Other contributions were derived from components of various projects such as one-time site designations, dike construction projects, and heave-measurement instrumentation. While not direct O&M benefits, these are benefits that have resulted from the DRP and are in the public interest.

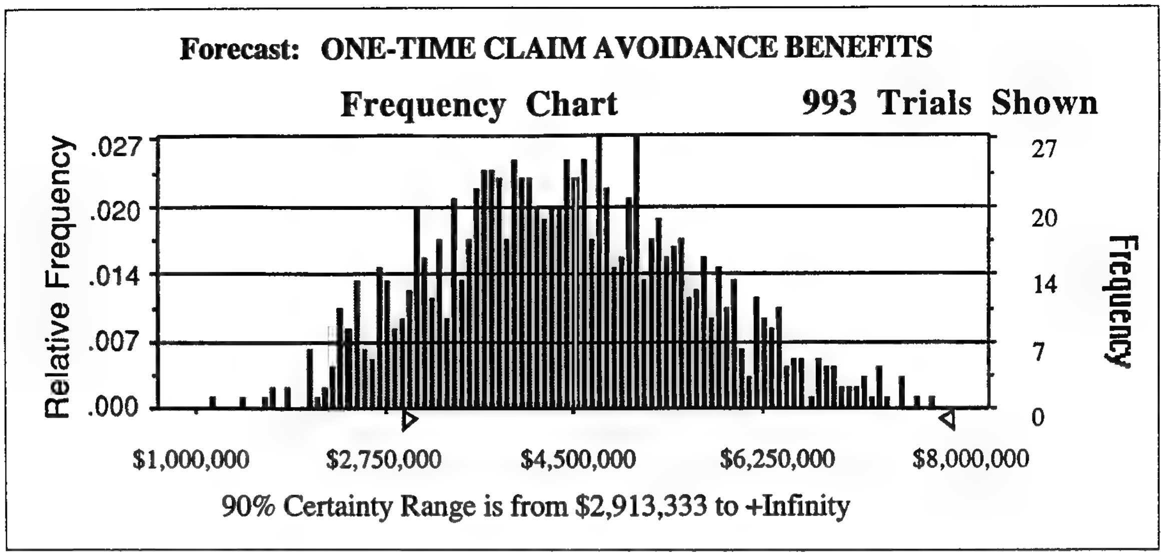

Figure 15. Simulation results for one-time claim avoidance benefits

Table 7 lists one-time non-O&M benefits (raw data); Figure 16 shows the data sorted by District.

Based on the simulations, one can have a 90-percent confidence that one-time non-O&M benefits that have occurred will equal $8,900,000 more in 1994 dollars (Figure 17).

Mean = $10,996,058
Standard deviation = $1,750,103
Coefficient of variation = 27%

Indirect Benefits

This last category of computed costs is included as an example of some of the indirect benefits that could be derived from DRP products. The magnitude of indirect benefits would be staggering. They would overshadow the direct benefits and, because of their "soft" nature, reduce confidence in the figures generated by this study.

The following is presented as an example of an indirect benefit of $5,800,000 that would result from using DRP capping products to assist in keeping the Mud Dump site open for disposal of sediment dredged from New York Harbor and classified as contaminated (category II).[1]

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[1] Based upon draft figures from the New York District's draft report, *Dredged Material Transportation Cost Analysis, 1993.*

Table 7
One-Time Non-O&M Benefits (Raw Data)

Product	District	Project	Benefit
Vertical Motion	LMN	Heave measurement	$15,000
DPR	NAN	Arthur Kill deepening	$132,000
Vertical Motion	NAN	Heave measurement	$15,000
Acoustic Profiler	NAO	Norfolk Harbor	$42,000
Draghead	NAO	Thimble Shoal	$115,000
Draghead	NAO	York Spit	$157,000
Draghead	NAO	York Spit II	$384,000
Draghead	NAO	Cape Henry	$99,000
Vertical Motion	NAO	Heave measurement	$15,000
Acoustic Profiler	NAP	Delaware River deepening	$115,000
Acoustic Profiler	NAP	Delaware Coast Beach Fill	$161,000
Acoustic Profiler	NAP	Townsends Inlet	$50,000
Acoustic Profiler	NAP	Delaware Bay Beach Fill	$75,000
Vertical Motion	NAP	Heave measurement	$15,000
Vertical Motion	NCB	Heave measurement	$15,000
Acoustic Profiler	NED	Boston Harbor deepening	$40,000
Vertical Motion	NED	Heave measurement	$15,000
Vertical Motion	NPP	Heave measurement	$15,000
Fate Models	NPS	Shemya AFB	$242,000
Fate Models	NPS	Shore protection structures	$81,000
Capping	NPS	Denny Way	$463,000
Draghead	NPS	Grays Harbor Draghead	$96,000
Vertical Motion	NPS	Heave measurement	$15,000
Draghead	SAC	Charleston Harbor deepening	$46,000
Vertical Motion	SAC	Heave measurement	$15,000
PLUMES	SAJ	Miami Site redesignation	$1,150,000
PLUMES	SAJ	Tampa Site redesignation	$1,150,000
PLUMES	SAJ	Fernandina Site redesignation	$1,150,000
PLUMES	SAJ	Canaveral Site redesignation	$1,150,000
Vertical Motion	SAJ	Heave measurement	$15,000
Bin Measure	SAM	Pensacola Homeport deepening	$166,000
Water Injection	SAM	Panama City Harbor	$2,483,000
Vertical Motion	SAM	Heave measurement	$15,000
Erodability	SAM	Dike construction	$1,073,000

(Continued)

Table 7 (Concluded)			
Product	**District**	**Project**	**Benefit**
Acoustic Profiler	SAM	Panama City Harbor deepening	$200,000
Vertical Motion	SAS	Heave measurement	$15,000
Vertical Motion	SAW	Heave measurement	$15,000
Capping	SPL	Marina del Rey	$758,000
Acoustic Profiler	SPL	Santa Barbara Harbor	$4,000
Vertical Motion	SPL	Heave measurement	$15,000
PLUMES	SPN	Naval Air Station Alameda	$234,000
Vertical Motion	SPN	Heave measurement	$15,000
SI/DDLS	SPN	Oakland Harbor	$192,000
SI/DDLS	SPN	Oakland Harbor surgery	$69,000
Acoustic Profiler	SWG	Galveston Beach Fill	$22,000
Draghead	SWG	Freeport Harbor	$269,000
Vertical Motion	SWG	Heave measurement	$15,000
Total			$12,608,000

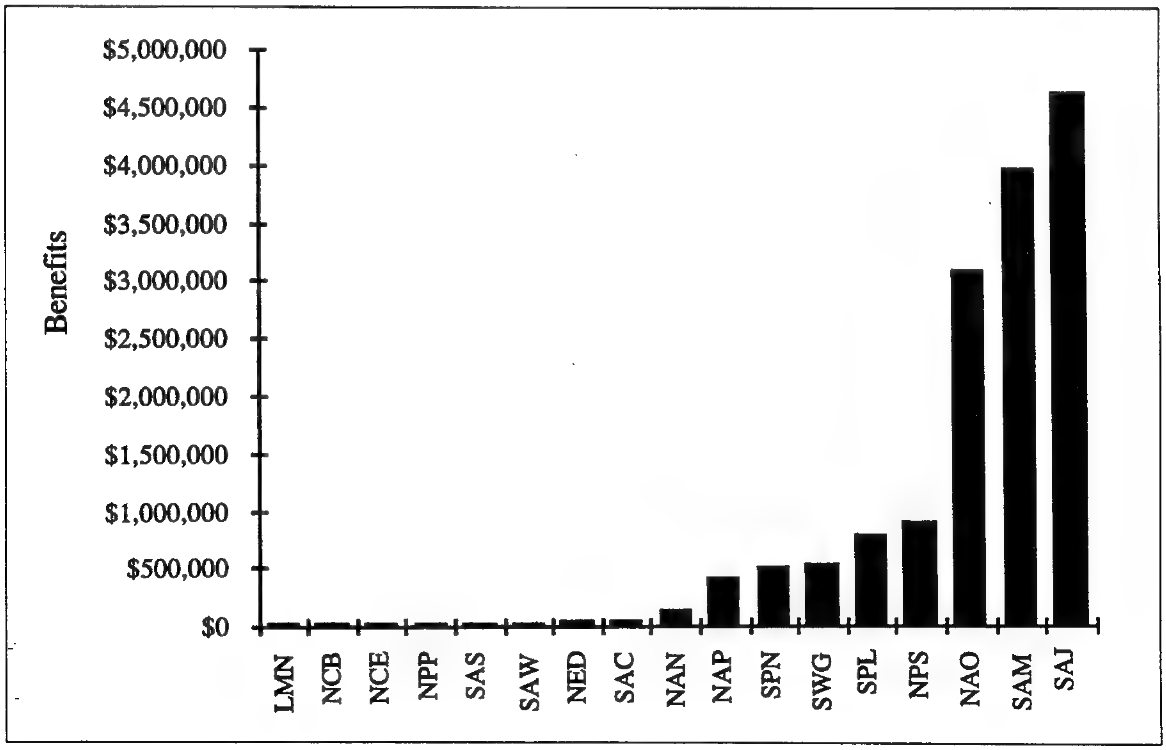

Figure 16. One-time non-O&M benefits sorted by Districts (raw data)

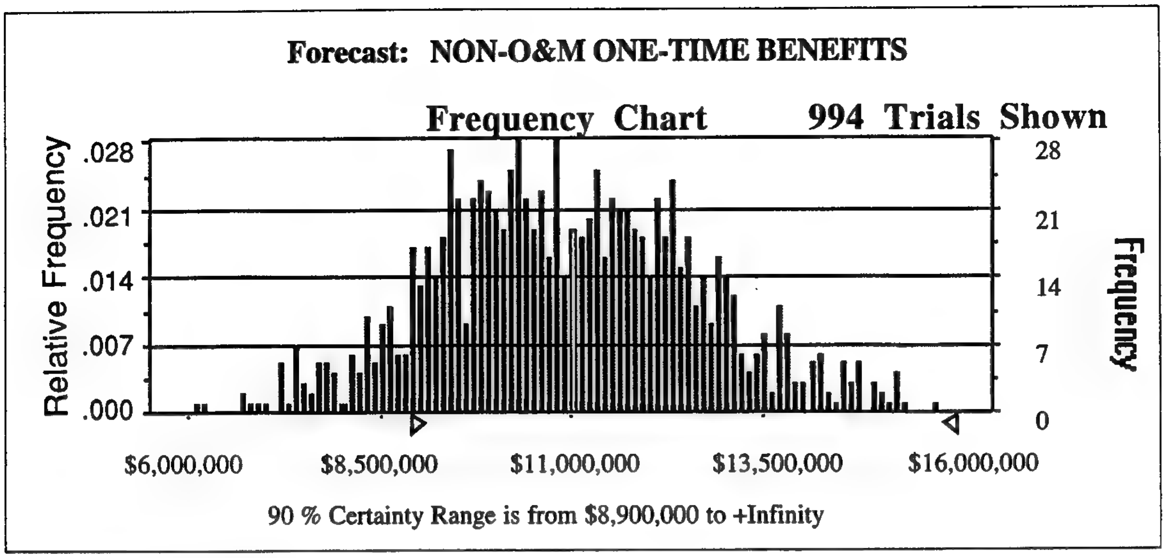

Figure 17. Simulation results from one-time non-O&M benefits

Total annual benefits of dredging NY Harbor:

Container ships	$77,450,000
Lightering costs	$11,647,000
Tanker delay costs	$ 6,845,698
Total annual benefits	$95,845,698
Percentage sediments, category II	5%
Total benefits lost to Mud Dump closure to category II material	$ 4,800,000
Eliminated environmental contracts (two studies at $500,000)	$ 1,000,000

There is a 90-percent assurance that $1,517,000 in indirect benefits will occur in this example case (Figure 18).

Summary of one-time benefits

Table 8 is a summary of all quantified one-time benefits (90-percent assurance estimates). These project benefits were generally realized over a 3-year period and annualized into 1994 dollars. If these were considered cyclical from a global viewpoint, the resultant 5-year savings would exceed $101,141,000.

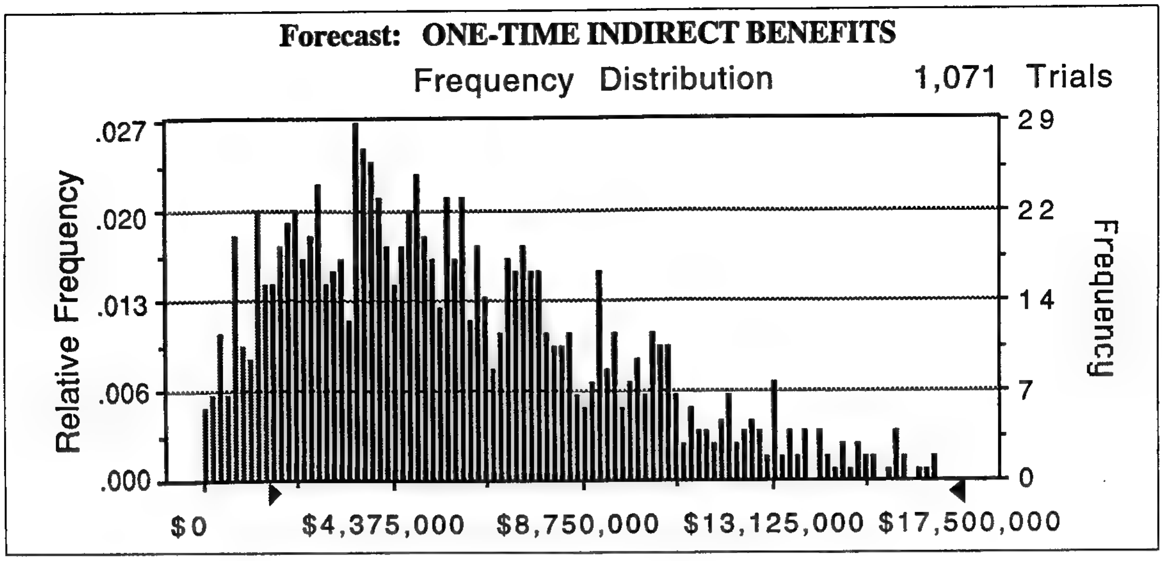

Figure 18. Simulation results for one-time indirect benefits

Table 8
Summary of one-time benefits, in 1994 dollars

One-time O&M benefits	$5,717,000
One-time claim avoidance benefits	$2,913,000
One-time non-O&M benefits	$8,900,000
Example one-time indirect benefits	$1,517,000
Total demonstrated one-time benefits	$19,047,000

8 Potential Benefits That Were Not Quantified

The following benefits were identified during the data collection phase of the DRP benefits analysis either by District/Division staff, WES researchers, or the benefits analysis team. These benefits were not quantified due either to a need for further investigation or more precise verification, or to a concern with possible ramifications involving litigation or other issues. They are sorted by District and technical area.

New Orleans District

Technical Area-1

There is a possible O&M direct benefit on the Atchafalaya River and Bar disposal site designation attributable to potential use of the numerical modeling products. The WES staff identified the potential benefits, but they were not pursued further.

Technical Area-2

There are possible O&M direct benefits on both the Calcasieu River/Pass and Atchafalaya River projects attributable to potential use of the fluid-mud products. The LMN staff feels that the products may facilitate their hydrographic survey operations, but more analysis needs to be done before any benefits can be calculated.

Technical Area-3

There are possible efficiency enhancement benefits on the hopper dredge Wheeler's Lower Mississippi River Baton Rouge and Calcasieu Pass projects attributable to the potential use of the modified draghead product. The LMN staff feels that more testing and analysis need to be done before any benefits can be calculated.

There are possible regulatory benefits on the Atchafalaya Bar, Mississippi River Gulf Outlet, and Calcasieu Pass projects attributable to potential use of the modified draghead product. The WES and LMV staffs feel the modified draghead could be used to avoid harming sea turtles during dredging operations, which would eliminate or reduce environmental monitoring requirements. However, the LMN staff feels that more testing and analysis need to be done before any benefits can be calculated.

There is a possible O&M direct benefit on the Red Eye Crossing Baton Rouge project attributable to potential use of the submersible pump product. Potential benefits were identified by WES staff but were not pursued further.

There are possible O&M direct benefits on the Three Rivers, Port Allen Forebay, and various New Orleans area dock projects attributable to potential use of the water injection dredging product. The LMN staff feels that the product compares favorably to hydraulic plant operations for these jobs. However, more site geometry planning and analysis need to be done before any benefits can be estimated.

Technical Area-5

There are possible O&M direct benefits from both the Mississippi River Gulf Outlet and Atchafalaya River or Bar open-water disposal site selection projects attributable to potential use of the site management methodology product. Potential benefits were identified by WES staff but were not pursued further.

New York District

Technical Area-2

There is a possible non-O&M direct benefit on the Kill Van Kull projects attributable to potential use of the sediment dredgeability determination product. The benefits analysis team and NAN staff feel that the product's use could have provided the contractor with more detailed sediment characteristics in the hope that long-term bid reduction might result. No calculations were made due to uncertainties involved with predicting contractor bids.

There is a possible claim avoidance benefit on the Kill Van Kull projects attributable to the actual use of the drilling parameter recorder product, as identified by WES staff. In the opinion of NAN staff, however, any benefits are not quantifiable.

Technical Area-4

There is a possible regulatory benefit on both the Mud Dump and Replacement Ocean Disposal Site attributable to potential use of the Silent Inspector product, as identified by the benefits analysis team. The benefits were not pursued further, however, due to the complexity of quantifying aspects of the regulatory process.

There is a possible regulatory benefit for the District permitting process attributable to potential use of the Silent Inspector product, as identified by NAN staff. The benefits were not pursued further, however, due to the complexity of quantifying aspects of the regulatory process.

Technical Area-5

There is a possible regulatory benefit on various New York Bay projects attributable to potential use of the capping methodology product, as identified by the benefits analysis team. The benefits were not pursued further, however, due to the quantification complexity and to the many external variables associated with contaminants disposal.

Norfolk District

Technical Area-1

There is a possible O&M direct benefit for the future Craney Island openwater alternate disposal site attributable to the numerical modeling products. NAO staff feel that a site will have to be found if and when the current upland site closes due to lack of capacity. However, calculations are not possible because more planning needs to be done before any benefits are estimated.

There is a possible O&M direct benefit for the plume monitoring procedure on District survey boats attributable to actual use of the PLUMES product. The benefits were identified by NAO staff but were not pursued further.

Technical Area-2

There is a possible non-O&M direct benefit for both the York River and Baltimore Channels new work projects attributable to potential use of the acoustic profiler product. Benefits were identified by the benefits analysis team but were not pursued further.

Technical Area-3

There is a possible O&M direct benefit on the Rudee Inlet project attributable to potential use of the eductor sand-bypassing product, as identified by NAO staff. The benefits were not pursued further due to the many technical and economic variables involved with a sand-bypassing project.

Technical Area-5

There is a possible non-O&M direct benefit on the Sandbridge non-Federal project attributable to potential use of the berm placement methodology product, as identified by NAO staff. Benefits were not calculated because more planning needs to be done; also, the project may not be authorized.

Philadelphia District

Technical Area-1

There are possible O&M and non-O&M direct benefits attributable to the numerical modeling products on several District projects, for which future disposal options might involve open-water placement. The staff at the U.S. Army Engineer District, Philadelphia (NAP) have identified both O&M and new work projects that may have their present upland or confined disposal areas filled to capacity in several years. Benefits were not calculated because more planning and analysis need to be done and it is too soon to tell which projects will be affected.

Technical Area-3

There is a possible efficiency enhancement benefit on the hopper dredge McFarland beach replenishment projects attributable to the single-point mooring product. Benefits were identified by WES staff but were not pursued further.

Technical Area-4

There is a possible efficiency enhancement benefit on all hopper dredge McFarland projects attributable to the production meter product. Benefits were identified by WES staff but were not pursued further.

Technical Area-5

There is a possible efficiency enhancement benefit on all hopper dredge McFarland projects attributable to the dredge plant manuals product. Benefits were identified by WES staff but were not pursued further.

There is a possible O&M direct benefit on the Upper Chesapeake Bay "G" West Disposal Site project attributable to the berm design methodology product, as identified by NAP staff. No benefits were estimated because the project design was already in completion.

Buffalo District

Technical Area-1

There is a possible O&M direct benefit on the Ashtabula River project attributable to potential use of the numerical modeling products. NCB staff identified potential benefits derived from having the ability to track contaminated river sediment. However, more analysis and planning need to be done before any calculations can be made.

There is a possible O&M direct benefit on the Toledo Harbor project attributable to potential use of the numerical modeling products. NCB staff identified potential product use in monitoring contaminated sediment transport. However, more analysis needs to be done before any calculations can be made.

There is a possible O&M direct benefit on the Ashtabula Harbor project attributable to potential use of the sediment erodability characteristics product. WES staff identified the benefits, but no estimates were made because the project is still in the planning phase.

Technical Area-2

There is a possible non-O&M direct benefit on the Ashtabula confined disposal facility (CDF) design attributable to potential use of the acoustic profiler product. NCB staff identified the benefit, but calculations were not pursued further because the explorations had just been completed.

Technical Area-3

There is a possible non-O&M direct benefit on the Toledo Harbor CDF fixed-mooring construction project attributable to potential use of the single-point mooring product. The benefits analysis staff felt that a single point mooring could have been substituted for the fixed mooring station, but no estimates were made because construction had already been completed.

Technical Area-5

There are possible non-O&M direct benefits on both the Toledo Harbor and Ashtabula Harbor projects attributable to the capping methodology product. Benefits were identified by the benefits analysis staff but were not pursued further.

Detroit District

Technical Area-2

There is a possible O&M direct benefit on the Lower Detroit River project attributable to potential use of the acoustic profiler product. NCE staff feel the product could be used to locate rock outcrop pinnacles on the river floor. The present system misses some of them, creating a navigation hazard. However, the NCE staff feels that more analysis would have to be done before any benefits could be quantified.

There is a possible non-O&M direct benefit on the St. Marys Channel project attributable to actual and potential use of the DPR product, as identified by NCE staff. No estimates were made, however, because the project was subject to ongoing changes that affected the exploration scope.

Rock Island District

Technical Area-3

There is a possible O&M direct benefit on the Mississippi River Savanna project attributable to actual use of the water injection dredging product. Benefits were identified by WES staff but were not pursued further.

Technical Area-4

There is a possible O&M direct benefit on various Mississippi River projects attributable to potential use of the DGPS product. The NCR staff identified possible benefits from simplified riverine survey operations, but they were not pursued further.

There are possible O&M and non-O&M direct benefits on various contract pipeline projects attributable to potential use of the production meter system product. The benefits analysis team feels that contractor efficiency could be improved upon with production meter monitoring; however, no estimates were made due to the complexity encountered with correlation of contractor performance and bid amount.

There are possible non-O&M direct benefits on various emergency dredging and levee building projects attributable to potential use of the production meter system product. The NCR staff feels that contractor performance and accuracy on emergency jobs, with no time for pre-work surveys, could be improved with monitoring. Again, however, no estimates were made due to the complexity encountered with correlation of contractor performance and bid amount.

New England Division

Technical Area-1

There are possible O&M direct benefits attributable to potential use of the PLUMES product on the New Haven Harbor project for environmental monitoring, and at the Massachusetts Bay Disposal Site for cap placement monitoring. The NED staff identified the benefits, but no calculations were made because more analysis needs to be done before the products can actually be used.

There is a possible non-O&M direct benefit from measurement of capping cover thicknesses on various projects attributable to potential use of the acoustic profiler product. NED staff feel that the product could be used as a monitoring tool to improve accuracy over past methods. No estimates were made, however, because NED staff feel that more planning needs to be done before any possible implementation.

Technical Area-3

There are possible O&M direct benefits on the Connecticut, Portsmouth, and Kennebec River projects attributable to potential use of the Water Injection Dredging product. NED staff feel the product could be a viable alternative to pipeline dredging; however, more analysis needs to be done before any estimates can be made.

Technical Area-5

There is a possible efficiency enhancement benefit on projects involving the hopper dredge Currituck attributable to potential use of the berm placement methodology product, as identified by NED staff. However, NED staff do not feel there are any quantifiable benefits at this time.

There is a possible non-O&M direct benefit on various projects attributable to potential use of the capping methodology product, as identified by WES staff. However, NED staff do not feel there are any quantifiable benefits at this time.

There are possible O&M direct benefits from use of the Disposal Area Monitoring System and on the Massachusetts Bay Disposal Site attributable to actual use of the site management methodology product, as identified by WES staff. However, NED staff do not feel there are any quantifiable benefits at this time.

Portland District

Technical Area-1

There are possible O&M direct benefits on both the Coos Bay and Mouth of the Columbia (MCR) projects attributable to potential use of the numerical transport modeling products. The benefits analysis staff feels the products might help in predicting or verifying past knowledge of mounding at these disposal sites. However, NPP staff does not feel that any estimates can be made at this time.

Technical Area-2

There is a possible claim avoidance benefit on the Coos Bay RM 4.0 project attributable to potential use of the acoustic profiler product. The benefits analysis team staff feel the product could have been used to locate an uncharted rock ledge and avoid a navigation hazard. However, the NPP staff does not feel that any quantification can be made at this time.

There are possible non-O&M direct benefits on both the Coos Bay and Columbia River new work projects attributable to potential use of the acoustic profiler product. The benefits analysis staff feels that a reduction in exploration scope might be attainable; however, the NPP staff feels that more analysis needs to be done before any estimates could be made.

There were possible O&M direct benefits on both the Dalles Lock and Dam and Columbia River Emergency Dredging projects attributable to potential use of the acoustic profiler product. The benefits analysis team staff felt that the product could have been used to positively identify rock quantities and to avoid excess mobilization costs. However, more analysis is needed before any quantification can be made.

Technical Area-3

There is a possible O&M direct benefit on the Port Orford project attributable to actual use of the submersible pump product, as identified by WES staff. No benefits were estimated when actual pump costs were found to be similar to those of a pipeline dredge on this job.

There is a possible efficiency enhancement benefit on the hopper dredge Essayons projects attributable to potential use of the single-point mooring product. The benefits analysis team identified the benefit but did not pursue it further.

Technical Area-4

There are possible O&M direct benefits on both the MCR and Coos Bay Entrance projects attributable to potential use of the Automated Real-Time Tidal Elevation System product, as identified by NPP staff. No benefits were estimated, however, because NPP staff feel that more analysis and planning need to be done.

There is a possible O&M direct benefit on all pipeline dredge Oregon projects attributable to actual use of the production meter product, as identified by the benefits analysis team and WES staff. No benefits were estimated, however, because the NPP staff feels that more analysis and planning need to be done.

There are possible efficiency enhancement benefits on the hopper dredges Essayons and Yaquina projects attributable to potential use of the Silent Inspector product, as identified by WES staff. The NPP staff feels the product could make the dredging process more efficient; however, no estimates can be made at this time.

Technical Area-5

There are possible efficiency enhancement benefits on the hopper dredges Essayons and Yaquina projects attributable to potential use of the dredge plant manuals product, as identified by WES staff. However, the NPP staff feels that no estimates could be made at this time.

There are possible O&M direct and regulatory benefits associated with the Columbia River Estuary Long Term Management Study projects and their potential use of any of the site management methodology products. However, the NPP staff feels that no estimates can be made at this time.

Seattle District

Technical Area-1

There is a possible non-O&M direct benefit on the U.S. Navy Everett Home Port project attributable to potential use of the numerical fate modeling product. The benefits analysis team feel the product could have had a favorable impact on avoiding extra costs involved with sensitive open-water

sediment disposal. However, the U.S. Navy staff feels that more analysis needs to be done before any estimates can be made.

Technical Area-2

There is a possible non-O&M direct benefit on the Grays Harbor new work project attributable to actual or potential use of the drilling parameter recorder product. Benefits were identified by WES staff but were not pursued further.

Technical Area-3

There is a possible regulatory benefit on the Grays Harbor projects attributable to potential use of the modified draghead crab-excluder product. The benefits analysis team feels the product could reduce operational costs, if perfected. However, the NPS staff feels that more analysis needs to be done before implementation.

Technical Area-5

There are possible non-O&M direct benefits on both the Metro Pier 53 and the Lower Duwamish River projects attributable to actual and potential use, respectively, of the capping methodology product. The benefits analysis team feels the product could be used to justify a cost-effective open-water disposal alternative to upland disposal. However, the NPP staff feels that more analysis and planning need to be done before any estimates can be made.

There are possible O&M direct and regulatory benefits from the various projects affected by the Puget Sound Dredged Material Disposal Analysis attributable to actual use of the site management product. The benefits analysis staff feel the product has contributed to an overall simplification of dredging and disposal operations. However, the benefits were not pursued further due to the complexity of quantifying aspects of the regulatory process.

Charleston District

Technical Area-1

There is a possible non-O&M benefit on any emergency shore replenishment project attributable to potential use of the single-point mooring product. WES staff feel the product could be used productively in the aftermath of a hurricane. However, the SAC staff feels no estimates can be made at this time.

Jacksonville District

Technical Area-3

There is a possible regulatory benefit on Canaveral Harbor attributable to potential use of the modified draghead product. The WES and SAJ staffs feel the project, presently being dredged by clamshell to avoid sea turtles, is ideally suited for hopper dredging. If the draghead design was perfected, dredging operations could be simplified and made safer for the turtles. However, the SAJ staff feels the benefits should not be pursued further at this time due to the operational and environmental complexity involved with the regulatory process.

There are possible O&M and non-O&M direct benefits on several Florida inlets and small harbors, including St. Lucie Inlet and Palm Beach Harbor-Lake Worth. The benefits are attributable to potential use of the eductor-sand bypassing product, as identified by SAJ staff. However, SAJ staff feel that more analysis and planning need to be done before any estimates are made.

There are possible O&M direct benefits on the Canaveral, Tampa, and Fernandina Harbor projects attributable to potential use of the single-point mooring product. Benefits were identified by the SAJ staff, but, in their opinion, the benefits were too complex to quantify at this time.

Technical Area-4

There are possible O&M direct and cost avoidance benefits on the Kings Bay-St. Marys Inlet project attributable to the ARTTES product. The SAJ and WES staffs both feel the product helps to enable continuing dredging operations in advance channel tidal conditions, possibly reducing over-dredging by verifying project depth, and possibly reducing contractor hydrographic survey-related changed condition claims. However, the SAJ staff feels the benefits should not be pursued further at this time due to the technical and operational complexity involved with the project.

Technical Area-5

There are possible O&M direct and regulatory benefits on the Kings Bay, Canaveral, Palm Beach, and Fort Pierce Harbor projects attributable to potential use of the berm placement methodology product. The SAJ staff feels the product is a viable alternative to on-beach placement in that contact with nesting sea turtles could be avoided. However, the SAJ staff feels the benefits should not be pursued further at this time due to the environmental complexity involved with the regulatory and operational processes of the jobs.

Mobile District

Technical Area-2

There are possible non-O&M direct benefits on the Gulfport, Mobile, Pascagoula, and Panama City Harbor projects attributable to actual use of the acoustic profiler product. The WES staff feels that a possible reduction in exploration scope for both new work and beach-fill identification could be attained with the product. However, the SAM staff does not feel there are any quantifiable benefits at this time.

There is a possible cost avoidance benefit on the Mobile Harbor project attributable to actual use of the acoustic profiler product. The WES staff feels that a possible reduction in contractor changed-conditions claims could be attained with the product. However, the SAM staff does not feel there are any quantifiable benefits at this time.

Technical Area-3

There are possible O&M direct benefits on the Black Warrior River and the Tombigbee Waterway projects attributable to potential use of the Water Injection Dredging product. The SAM staff feels the product may compare favorably to the pipeline physical plant, but more analysis needs to be done before any benefits can be estimated.

Technical Area-5

There is a possible O&M direct benefit on the Pensacola Harbor project attributable to the berm placement methodology product. However, the SAM staff feels more planning needs to be done before any possible implementation.

Savannah District

Technical Area-1

There are possible O&M direct benefits on the Savannah and Brunswick Bar projects attributable to potential use of the PLUMES product. The SAS staff feels there will be a need to monitor the proposed nearshore disposal operations for both projects; however, more analysis and planning need to be done before any estimates are made.

Technical Area-2

There are possible non-O&M direct benefits on the Savannah and Brunswick Ship Channel new work projects attributable to actual and potential use, respectively, of the acoustic profiler product. However, the SAS staff does not feel there are any quantifiable benefits at this time.

There is a possible non-O&M direct benefit on the Kings Bay project attributable to potential use of the drilling parameter recorder product. Benefits were identified by the WES staff but were not pursued further.

Technical Area-3

There are possible O&M direct benefits on the Savannah and Brunswick Ship Channel projects attributable to potential use of the hopper bin monitoring product. The SAS staff feels there could be a need to monitor dredging operations to avoid contractor payment problems for both projects; however, more analysis and planning need to be done before any estimates are made.

There is a possible O&M direct benefit on the Savannah River project attributable to potential use of the single-point mooring product. The SAS staff feels the product could play a role in creation of a bird sanctuary with dredged material. However, benefits were not pursued further.

There is a possible non-O&M direct benefit on the U.S. Navy Kings Bay project attributable to potential use of the water injection dredging product. The SAS staff feels the product allows for removal of sediment from the Degaussing Facility base, an operation not possible by conventional dredging means. However, the SAS staff does not feel the benefits should be pursued further at this time due to the complexity involved with the operational aspects of the job.

Technical Area-4

There is a possible cost avoidance benefit on the Savannah Ship Channel Entrance project attributable to potential use of the ARTTES product. The SAS staff feels the product could help to reduce or avoid a portion of potential differing-site claims related to annual contractor hydrographic surveys. However, benefits were not pursued further due to the quantification complexity and many external variables associated with predicting the effects of litigation.

There are possible cost avoidance benefits on the Savannah Ship Channel Entrance and Brunswick Ship Channel Entrance projects attributable to potential use of the Differential Global Positioning System product. The SAS staff feels the product could help to reduce or avoid a portion of potential differing-site claims related to annual contractor hydrogrphic surveys. However, more analysis and planning need to be done before any estimates are made.

Technical Area-5

There is a possible non-O&M direct benefit on the Brunswick Harbor and Ship Channel project attributable to the capping methodology product, as identified by the benefits analysis staff. Benefits were not calculated because it is too soon to tell whether or not any contaminants will be identified as posing environmental problems and requiring special removal and treatment.

There is a possible O&M direct benefit on the Brunswick Harbor Ship Channel Long Term Management Study through potential use of any of the site management methodology products. However, no estimates could be made at this time due to a need for further analysis.

Wilmington District

Technical Area-2

There is a possible O&M direct benefit on the Cape Fear River-Wilmington Harbor Ship Channel Bar project attributable to potential use of the fluid-mud navigable depth determination product. The staff at the U.S. Army Engineer District, Wilmington (SAW) feel the product could help to define accurately the project design depth. However, more analysis needs to be done before any estimates are made.

There is a possible non-O&M direct benefit on the Wilmington Harbor Ship Channel new work project attributable to potential use of the drilling parameter recorder product, as identified by the WES staff. However, more analysis needs to be done before any estimates can be made.

Technical Area-3

There are possible regulatory benefits on the Wilmington and Morehead City Harbor projects attributable to potential use of the modified draghead product. The WES staff feels that operational monitoring simplification could be attained with use of the perfected product in avoiding sea turtles. However, the benefits were not pursued further.

Technical Area-5

There is a possible efficiency enhancement benefit on all hopper dredge Currituck projects attributable to the dredge plant manual product, as identified by WES staff. However, benefits were not pursued further.

There are possible O&M direct benefits on both the Wilmington and Morehead City Harbor projects attributable to potential use of the berm placement methodology product. The SAW staff feels the product will provide a viable

alternative to present disposal methods; however, more analysis and planning need to be done before any estimates could be made.

Los Angeles District

Technical Area-3

There is a possible O&M direct benefit on the Morro Bay project attributable to the modified draghead product. The SPL staff feels the product could allow for increased operational efficiency on part of the project's material. However, benefits were not pursued further due to difficulty in defining an exact volume of the applicable material.

There is a possible O&M direct benefit on the Oceanside Harbor project attributable to potential use of eductor sand-bypassing product, as identified by the SPL and WES staff. Benefits were not pursued further due to the large technical, economic, and political variables involved with sand bypassing.

There are possible O&M direct benefits on the Santa Barbara and Ventura Harbor projects attributable to potential use of eductor sand-bypassing products. Benefits were identified by the SPL staff; however, more analysis and planning need to be done before any estimates can be made.

San Francisco District

Technical Area-1

There is a possible O&M direct benefit on the Humboldt Bay Open Ocean Disposal Site attributable to actual use of the numerical fate model product as identified by the WES staff. However, benefits were not pursued further.

Technical Area-2

There is a possible O&M direct benefit on the Mare Island Strait project attributable to potential use of the fluid mud navigable depth determination product. The SPN staff feels the product could be used to help facilitate the hydrographic survey process and monitor any contractor overpayment. However, benefits were not pursued further.

There are possible non-O&M direct benefits on the Oakland Harbor new work projects attributable to actual and potential use of the acoustic profiler product as identified by WES staff. However, benefits were not pursued further due to the large economic and political variables involved with the project.

There are possible non-O&M direct benefits on both the Humboldt and Richmond Harbor new work projects attributable to potential use of the acoustic profiler product as identified by SPN staff. However, the benefits were not pursued further because more analysis and planning need to be done before any estimates can be made.

There are possible O&M direct and claim avoidance benefits on the San Francisco Bay rock formation removal projects attributable to potential use of the drilling parameter recorder product. The SPN staff feels the product could help define the rock-material properties and facilitate their removal, if necessary. However, benefits were not pursued further because more analysis and planning need to be done before any estimates can be made.

Technical Area-3

There are possible O&M direct benefits on the San Francisco Bar and Humboldt Harbor projects attributable to the modified draghead product. The SPN staff feels the product may provide better operational efficiency, if perfected. However, the benefits were not pursued further because more analysis needs to be done before any estimates can be made.

There is a possible O&M direct benefit on the Berkeley Marina project attributable to potential use of the submersible pump product. The SPN staff identified the benefit, but it was not pursued further.

Technical Area-5

There is a possible non-O&M direct benefit on the Oakland Harbor new work project attributable to potential use of the capping methodology product as identified by the benefits analysis team. However, benefits were not pursued further.

There are possible O&M direct and regulatory benefits associated with the San Francisco Bay Long Term Management Study projects and their potential use of any of the site management methodology products. However, the SPN staff feels that no estimates can be made at this time.

Galveston District

Technical Area-2

There are possible non-O&M direct benefits on Houston and Brownsville Ship Channel new work projects attributable to potential use of the acoustic profiler product as identified by WES and the benefits analysis team. The products may reduce the scope of exploration; however, the SWG staff feels

that more analysis and planning need to be done before any estimates can be made.

Technical Area-5

There are possible indirect benefits on the various projects involving near-shore disposal of dredged material, including Galveston Brazos Island, attributable to the berm placement methodology product. The SWG staff feels that much benefit is gained in the form of positive public opinion and relations; however, no calculations were made due to uncertainties involved with quantifying public sentiment.

9 Potential Benefits That Were Transferable

During the course of this study, several District staff members identified quantifiable benefits that, in the opinion of the benefits analysis team, could also pertain to another District or to several others with similar projects or problems. These quantified benefits included in the final report were identified during the District site visits and subsequent follow-up phone conversations and were calculated as a result of District or WES staff input.

The products considered by the benefits analysis team to have applications in other Districts in addition to the projects cited earlier are given in the tabulation that follows.

Technical Area 1

Numerical fate and transport models

• Calc Sheet	NCR1
• Project(s)	Various riverine pipeline dredge operations
• Benefit	Simplified in-river discharge mixing-zone monitoring
• Comment	There is a potential related use on other District's riverine pipeline projects

• Calc Sheet	NPS1
• Project(s)	Cedar River and other sensitive disposal issue projects
• Benefit	Reduced litigation related administration and design time
• Comment	There is potential related use on other District's legally challenged disposal projects

Plume monitoring system

• Calc Sheet	SAJ2
• Project(s)	Various open-water site designations

- Benefit — Eliminated designation procedure expenditure
- Comment — There is a potential related use on other District's disposal sites under environmental pressure

Technical Area 2

Acoustic profiler

- Calc Sheet(s) — NAP1ABCD
- Project(s) — Delaware River Deepening/Beach Fill
  Delaware Coast Beach Fill
  Delaware Bay Beach Fill
  Townsons Inlet Beach Fill
- Benefit — Reduced scope of geotechnical exploration
- Comment — There is a potential related use on other District's new work or beach sand location projects

Technical Area 3

Bin monitoring efficiency

- Calc Sheet — LMN2
- Project(s) — Hopper dredge Wheeler various projects
- Benefit — Automated dredge data logging procedure
- Comment — There is a potential related use for hopper dredges Essayons, McFarland, and Yaquina

- Calc Sheet — LMN3
- Project(s) — Mississippi River Gulf Outlet
  Calcasieu River
  Southwest Pass
- Benefit — Improved rental contract overflow efficiency monitoring
- Comment — There is a potential related use on other District's hopper rental projects

- Calc Sheet(s) — NAO7, SAM2, SPN3
- Project(s) — Chincoteaque Inlet
  Thimble Shoal
  Cape Henry
  Mobile Harbor/Bay
  Humboldt Harbor
- Benefit — Reduced manual monitoring of hopper dredge operations
- Comment — There is a potential related use on other District's hopper dredging projects

Single-point mooring buoy

- Calc Sheet NPS9
- Project Hopper dredge Essayons Grays Harbor South Beach
- Benefit Increased onshore replenishment efficiency
- Comment There is a potential related use on other District's beach onshore placement projects

Water injection dredging

- Calc Sheet SAM3
- Project Panama City Harbor
- Benefit Increased operational efficiency
- Comment There is a potential related use on other District's potential water injection applicable projects

- Calc Sheet SWG5
- Project(s) Houston Ship Channel
  Matagorda Ship Channel
- Benefit Reduced dredging scope
- Comment There is a potential related use on other District's potential water injection applicable projects

Technical Area 4

Global positioning system

- Calc Sheet NCB4, NCE5, NPP5, SAJ6, SAW3, SPN6, SWG8
- Project(s) Hydrographic survey and positioning setup
- Benefit Improved hydrographic survey crew time efficiency
- Comment There is a potential related use on other District's applicable survey operations

- Calc Sheet(s) LMN7, NPS12
- Project(s) Mississippi River Gulf Outlet
  NPS Entrance Channels
- Benefit Reduced project-depth verification time and volume
- Comment There is a potential related use on other District's entrance-channel dredging projects

- Calc Sheet NPP1
- Project Various projects using hydrographic survey transponders
- Benefit Reduced loss from theft of shore transponder stations
- Comment There is a potential related use on other District's survey operations in crime-exposed areas

Production meter system

- Calc Sheet ORL1
- Project Evaluation of contract pipeline dredge performance
- Benefit Reduced litigation or cost overruns
- Comment There is a potential related use on other District's contract pipeline projects

Silent Inspector System

- Calc Sheet(s) NPP9, SPN8A
- Project(s) Various projects using a Silent Inspector System
- Benefit Optimized contract data analysis and recording
- Comment There is a potential related use on other District's projects using a Silent Inspector System

- Calc Sheet(s) SPN8BC
- Project(s) Various projects using a Silent Inspector System
- Benefit Reduced contract dredging-related litigation
- Comment There is a potential related use on other District's projects using a Silent Inspector System

- Calc Sheet SPN8F
- Project(s) Various projects using a Silent Inspector System
- Benefit Reduced contract dredging short dumping accusations
- Comment There is a potential related use on other District's projects using a Silent Inspector System

- Calc Sheet SPN8G
- Project(s) Various projects using a Silent Inspector System
- Benefit Increased contract-dredging operational efficiency
- Comment There is a potential related use on other District's projects using a Silent Inspector System

Technical Area 5

Dredge plant engineering manuals

- Calc Sheet LMN8
- Project(s) Hopper dredge Wheeler various projects
- Benefit Simplified hopper-dredge operational administration
- Comment There is a potential related use for hopper dredges Essayons, McFarland, and Yaquina

Site management methodology

- Calc Sheet NAO10
- Project Wolf Trap Alternate Site
- Benefit Reduced disposal site design and planning effort
- Comment There is a potential related use on other District's disposal site designation projects

Technology transfer

- Calc Sheet SAM-staff
- Project Contractor performance claim
- Benefit Reduced or eliminated litigation expenses
- Comment There is a potential related use on other District's actual or potential projects affected by suspect litigation

10 Environmental Benefit Valuation Techniques

Philosophy of Benefit Value

An objective at the early stages of this project was to attempt to quantify environmental benefits of the DRP. Although the DRP has been responsible for considerable environmental enhancements, these benefits are difficult to measure directly. Appendix A presents the reader with a comprehensive bibliography of environmental quantification procedures for future research.

Environmental benefits are primarily intrinsic in nature. Where environmental benefits are sought, therefore, it is expected they will be done so in the absence of a market measure. Economic valuation techniques for measuring environmental benefits can be identified through:

a. *Surrogate markets.* Finding a market in some other good or service that is influenced by the environmental non-market good. An example could be beach replenishment using berm technology. A surrogate market might be considered to exist in use of the beach for tourism.

b. *Market creation using questionnaires to measure preference.* Surveying to measure what individuals may be willing to accept in compensation for an environmental gain or loss.

c. *Dose-response data linked to valuation.* Identifying a relationship between some level of environmental change (usually of pollution) and physical change to the ambient environment. A monetary value can be assigned to the loss, which is in turn associated to the environmental damage.

d. *Public preference identification.* Identification of social preferences as they are reflected in social norms, regulations, and legislation.

These four techniques were presented in a report of the Organization for Economic Cooperation and Development for estimating benefits of

environmental measures.[1] Observations as to why benefit estimation techniques are used included stimulation of awareness, justification of a decision, and evaluation of regulations.

Benefit Value Considerations for Districts

The derivation of benefit considerations was established by direct questioning of the Districts regarding the use of DRP products. Potential uses and reasoning varied for each District. The alternative benefit measures used included:

- Alternative costs.
- Regional benefits.
- Direct costs.
- Ecosystem loss.
- Cost of loss/elimination.
- Cost savings.
- Property value.
- Worth.

A summary of District considerations regarding environmental benefits is presented in Table 9. Several of these issues which generated direct or indirect benefits as a result of the DRP, have been included in the main body of the study.

Related Environmental Assessment Methodologies

The development of environmental assessment methods has evolved from work in five areas: land-use planning tools, benefit-cost analysis, multi-objective analysis, checklists and matrices, and modeling and simulation. Each of the methodologies included in this annotated bibliography either directly applied or adapted one or more of the above assessment methods. Hyman and Stiftel (1988) conducted a comprehensive investigation of environmental assessment methodologies. These methodologies are reviewed in brief in the annotated bibliography. They provide possible approaches to measuring environmental value for decision makers, and range in the level of effort needed and in their technical content.

The Corps' dredging program provides unique constraints that must be considered. First of all, there is considerable diversity among the various Districts in the nation, each with a different dredging agenda. Diversity within the Districts themselves (between design functions and operations for

[1] Organization for Economic Cooperation and Development. (1992). *Benefit Estimation.*

Table 9
Environmental Benefit Considerations for Various Districts

District	Environmental Benefit
Buffalo	Alternative costs to upland disposal
Detroit	Regional benefits of proving legitimacy of proposed dumpsite
	Benefits from avoiding upland disposal
Jacksonville	Cost of protecting the ecosystem
	Technologies utilized to protect the ecosystem
Los Angeles	Direct cost of capping versus benefits to the region
	Alternative disposal costs
Portland	Loss issue to the fishing industry because of salmon migration problem
	Cost of alleviating salmon migration problem
	Cost savings of do-nothing scenario with respect to salmon migration problem
New York	Direct cost of capping versus regional benefits
	Alternative disposal costs
	Direct costs of berms versus the benefits of beach replenishment
	Alternative costs of beach protection measures
	Worth of beach-front property where a do-nothing alternative is considered
	DRP technology impact with respect to opinion on present and potential dump sites
San Francisco	Costs of maintaining a smaller dredging window
	Costs of eliminating dredging
	Improved environmental opinion from DRP whereby dredging operations will continue
Seattle	Crab loss issue presents an environmental loss to the fishing industry
	Cost of alleviating crab loss problem
	Cost savings presented with respect to a do-nothing scenario regarding crab loss
	Regional benefits of validating the legitimacy of a proposed dump site

example) make it prohibitively difficult to develop universal measurement schemes.

The methods, although flexible, introduce subjective judgement into the process through the people used to measure value (or benefit). Assessment of environmental effects is always subjective. It lies with the decision-maker to decide whether a subjective, but structured process, may offer more to the measure of benefit than a procedure that attempts to minimize subjectivity by documenting facts of the dredging practice.

The multiple objectives needed to measure risk can be obtained by several of the methodologies, especially the goals-achievement matrix (Hill and Alterman 1968) and the applied decision analysis (Keeney and Raiffa 1976). Nonetheless, the quality of measurement objectives would be obscured by the diversity in the Districts. It is therefore recommended that a much less structured approach be incorporated that will address factual information while at the same time measuring risk in projection of benefits into the future. The adaptive techniques used by Holling (1978) provide a much stronger basis for fact-finding and evaluation, as would be desired in a study of environmental benefits.

11 Results and Conclusions

In performing this study of the benefits attributable to the DRP, several important facts were apparent. First, DRP technology has not been transferred uniformly, for several reasons. The most important reason is the age of the program. It is reaching the end of its research phase; results are still being obtained. Technology is transferred over time and it is still early in the DRP's technology transfer phase. The other reason is that different Districts faced different problems at different times. Districts seek experts from the DRP to assist in immediate problems. If those immediate problems can be mitigated by DRP products, then there is a strong tendency to use that product in the District when it is of immediate use.

The second glaring fact was that DRP technology was transferred early to those Districts that participated in the research and served as test beds for research projects. WES researchers on those test bed projects developed relationships with the specific Districts that tested their products, and the Districts' enthusiasm for those products was evident.

The DRP, in its short life, has resulted in considerable monetary benefits to the Corps of Engineers. The procedures used in this benefits analysis represented a "bottom-up" approach. The dredging program for fiscal years 1989 through 1992 was chosen as the test population. Each project in the Corps program for 21 Districts was examined with respect to the following questions:

a. Was a DRP product used on the project?

b. Did the potential exist for use of a DRP product on that project?

If the answer to either question was yes, an estimated cost was developed for that project and compared to its actual cost. The difference between the estimated and actual cost was the "raw" benefit. These "raw" benefits were separated into annual benefits and one-time benefits. These two categories were further divided into O&M direct benefits; non-O&M direct benefits; cost avoidance benefits; mission and efficiency enhancement benefits; and indirect benefits.

O&M annual and one-time benefits were isolated because the DRP was funded from the Corps of Engineers O&M budget.

Recognizing that this type of analysis is steeped in uncertainty, the temptation for developing a single point estimate for benefits was rejected in favor of a stochastic approach whereby "lower bounds" for the benefits were estimated. A Monte Carlo simulation approach was used to account for the uncertainty inherent in each "raw" benefit estimate. Probability distributions associated with each benefit estimate were assumed based on the experience and judgment of the authors, the DRP staff, and District personnel. A large number of simulations were performed and relative frequency histograms of benefits were developed. The lower bound estimates are those numerical values that have a 90-percent probability of being exceeded. Results are conservative estimates of the benefits.

Annual O&M direct benefits should exceed	$11,200,000
Five-year O&M direct benefits should exceed	$64,700,000
Annual regulatory benefits should exceed	$413,000
Annual claim avoidance benefits should exceed	$149,000
Annual non-O&M direct benefits should exceed	$4,677,000
The resulting total five-year benefits for all ANNUAL benefits should exceed	$100,586,000

The primary goal of the DRP benefits analysis study was to gauge the effect of dredging research and development on the Corps-wide O&M program, which is conducted largely on a cyclical basis. However, while conducting the District field data-collection visits, it became apparent to the benefits analysis team that non-continuous projects were affected equally as much, if not more so, than those that occur on a regular basis. Significant benefits were quantified for both non-Federal and Federal new work and O&M projects. These benefits were one-time occurrences on projects with no dredging cycle.

Attempting to project benefits into the future for one-time projects is difficult. Since there is no repeatability within each District, there could be no way to expect any effect other than the one-time occurrence within the District.

However, if a global rather than local view of one-time benefits is considered, then benefits could be projected. For instance, a certain District may have scheduled a new work project in a certain year. This project may use DRP technology from which benefits could be produced. The project would not occur within that District again at a regular interval. Several of the other 30 or so dredging Districts, however, could have new work projects ongoing during the times that any one District does not. From a Corps-wide perspective, all of these new work projects could be collectively considered as producing continuous benefits. These benefits could then be analyzed and

simulated for the entire Corps dredging program. Each "lower bound" estimate has a 90-percent assurance of being exceeded.

One-time O&M benefits should exceed	$5,700,000
One-time claim avoidance benefits should exceed	$2,900,000
One-time non-O&M benefits should exceed	$8,900,000
Total one-time benefits should exceed	$17,500,000

Indirect benefits of the DRP, if calculated, would be so large as to overshadow the benefits calculated above. Therefore, except for one special example of indirect benefits, none were calculated. Although their existence is certain, the calculation of indirect benefits would contain uncertainties orders of magnitudes greater than the other benefits. The authors feel that the addition of indirect benefits would lessen confidence in the results of this study.

Chapter 8 discussed additional benefits that were not quantified because further extensive investigation was required, litigation was involved, or budgetary entanglements existed. These are listed by District.

During the course of this study, the benefits team identified quantifiable benefits that could also pertain to another District or to several others with similar projects or problems. These quantified benefits presented in Chapter 9 were identified during District site visits and subsequent follow-up conversations and were calculated as a result of District or WES staff input.

An objective in the early stages of this study was to attempt to quantify environmental benefits of the DRP. Although the DRP has been responsible for considerable environmental enhancements, these benefits are difficult to measure directly at present. Chapter 10 was added to give the reader a comprehensive bibliography of environmental quantification procedures for possible future quantification attempts.

Finally, this study is a "first of its kind" effort to attach benefits to the results of a Federal research program. Many different approaches were considered. The choice was ultimately between a "top-down" versus a "bottom-up" approach. While individual estimates can and should be questioned, the stochastic approach used in this report should provide a comfort level that the procedure is sound and the results reasonable.

References

Dee, N., et al. (1972). "An environmental evaluation system for water resources planning," Report PB-208822, National Technical Information Service, Springfield, VA.

Duke, K. M., et al. (1977). "Environmental quality assessment in multi-objective planning," National Technical Information Service for U.S. Bureau of Reclamation, Springfield, VA.

Fabos, J., et al. (1978). "The METLAND landscape planning process: Composite landscape assessment, alternative plan formulation and plan evaluation," Research Bulletin 653, Agricultural Experiment Station, University of Massachusetts, Amherst.

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Leopold, L., et al. (1971). "A procedure for evaluating environmental impact," Circular 645, U.S. Geological Survey, Washington, DC.

McHarg, I. (1969). *Design with nature.* Natural History Press. New York.

Solomon, C., et al. (1977). "Water resources assessment methodology: Impact assessment and alternative evaluation," Technical Report Y-77-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Sorenson, J. (1971). "*A framework for identification and control of resource degradation and conflict in the multiple use of the coastal zone,*" Technical Report, Dept. of Landscape Architecture, University of California, Berkeley.

Appendix A Annotated Environmental Benefits Bibliography

Land suitability map overlays

McHarg, I. (1969). *Design with nature.* Natural History Press, New York.

McHarg developed a systematic ecological planning process to aid in the screening of sites or routes for further development projects. His process took into account certain basic concerns: aesthetic quality; productivity of the land under consideration for agriculture; maintainability of ecological balance; and potentially hazardous use of the land. The methodology is quite simple. Separate studies are conducted to identify the attributes that bear significance for each study. Then, for each attribute, a suitability map is drawn with various shades of gray representing the severity of the constraints. Each map (drawn on a transparency) is then overlaid with the other attribute maps. The result is a map of the area questioned showing its suitability of use. Although the approach is relatively straightforward, it does not provide a causal picture of what is happening. It is also static in nature in that it does not provide a picture of future possibilities.

METLAND - the metropolitan landscape planning model

Fabos, J., et al. (1978). "The METLAND landscape planning process: Composite landscape assessment, alternative plan formulation and plan evaluation," Research Bulletin 653, Agricultural Experiment Station, University of Massachusetts, Amherst.

The metropolitan landscape planning model is an extension of McHarg's model. It provides information regarding spatial comparability regarding environmental quality. The METLAND process uses computational technology for generating and displaying alternative plans, and it sets up goal attainment by measuring efficiency benefits and costs. The process sets up value profiles by conducting landscape assessment, ecological compatibility, and public service assessment. Among its value sets, the model produces

alternatives by emphasizing community values with a high emphasis on environmental issues. The overall approach of the METLAND procedure is to suggest a pattern of development rather than to model the development process. As with McHarg's model, it is static in nature.

Leopold matrix

Leopold, L., et al. (1971). "A procedure for evaluating environmental impact," Circular 645, U.S. Geological Survey, Washington, D.C.

The Leopold matrix was developed by the U.S. Geological Survey as a systematic framework for environmental assessment. The procedure focuses on the use of a matrix that is 100 X 88 columns, representing activities that may cause an environmental impact versus rows of environmental quality variables. These variables are grouped into categories that include physical and chemical attributes, biological attributes, cultural attributes, and ecological attributes. The procedure is initiated with an expert marking those activities that may have an impact. Then each activity is measured according to both the magnitude and importance of the impact (on a scale of 1 to 10). A simple summation of rows and columns provides an indicator for significant factors in the assessment. This methodology has been used by the FAA for airport planning and by the California State Water Resource Control Board, among others. The method does not provide a means of risk measurement, although it may be argued that risk is factored into ratings. It also relies very heavily on subjective expert evaluations.

Environmental evaluation system

Dee, N., et al. (1972). "An environmental evaluation system for water resources planning," Report PB-208822, National Technical Information Service, Springfield, VA.

The environmental evaluation system was developed at Batelle-Columbus Laboratories to enhance the utility of environmental impact statements for the U.S. Bureau of Reclamation. The methodology is quantitatively based. It utilizes an aggregate index that stems from four broad categories comprising ecology, environmental pollution, aesthetics, and human interest. These categories are sub-structured into 18 sub-categories with a total of 78 attributes over which the index is measured. A value function is assigned to each attribute as well as a distributed weight. The values are scaled, and this measure is multiplied by the weight to provide an overall environmental impact unit value. These units may be summed for various projects and compared. The approach has been used on the Bear River Basin. The technique is weak in its use of the multi-attribute approach, and it is not time-variant. Furthermore, it does not have the ability to measure risk across the project constraints.

Environmental quality assessment method

Duke, K. M., et al. (1977). "Environmental quality assessment in multi-objective planning," National Technical Information Service for U.S. Bureau of Reclamation, Springfield, VA.

This method was developed for the U.S. Bureau of Reclamation in an attempt to modify the Environmental Evaluation System (Dee et al. 1972). This modified approach does not focus upon the use of weights and indices. Instead it relies more heavily upon physical measurements and qualitative descriptions of impacts. The environmental factors to be used are identified by a group panel who proceed to assign measurement boundaries for each. Matrix modeling is used to select specific factors deemed relevant, and baselines and future measurements are assigned. An environmental effect is calculated to be the measure with and without project effects. While the approach fails to recognize risk, it applies a stronger temporal value judgement to the estimated measures than does the environmental evaluation system. The method fails to recognize indirect effects, yet the procedure cleverly separates facts from value judgements, and it uses explicit criteria to evaluate the data.

Water resources assessment method

Solomon, C., et al. (1977). "Water resources assessment methodology: Impact assessment and alternative evaluation," Technical Report Y-77-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Water resources assessment methodology was developed by the U.S. Army Corps of Engineers. Its objective was to develop a scheme to conform to the requirements of the U.S. Water Resources Council. This method takes the same approach used by the environmental evaluation system (Dee et al. 1972). It uses value measurement through scaling and weight factors. The procedure is based upon accounts: the environmental quality account, the national economic development account, the social wellbeing account, and the regional development account. The approach provides critical variables for each account. A variety of techniques can be used to select scaling factors, which in turn are used to multiply to an impact and to finally get alternative choice coefficients. Individual scaled impact scores are assigned with a relative rating. Multiplying the relative rating with the alternative choice coefficients provides measures for all coefficients. These composite scores are left alone for comparison of the alternatives. The technique has been used in the Tensas River Basin. It provides a means towards observing alternatives and relating to their relative importance. It also provides an approach to assess the strengths and weaknesses of alternatives. The methodology has not been applied for various reasons. Perhaps the methodology is too complex and would not apply well for use at the District level.

Wetland evaluation system

Galloway, G. (1978). "Assessing man's impact on wetland," Report 78-135, Water Resources Research Institute, University of North Carolina, Raleigh, NC.

The Wetland evaluation system was developed for the U.S. Army Corps of Engineers to assist in assessing environmental impacts of dredged material filling of wetlands prior to issuing permits under Section 404. To implement the system, an interdisciplinary group is gathered to categorize the study area. Nine evaluation factors are used: endangered species habitat; the quantity and quality of aquatic ecosystems; terrestrial ecosystems; waterfowl; uniqueness; appearance; natural protection against flood and storm waves; life-cycle support through water assimilation and oxygenation; and hydrogenation; historical, and cultural factors. The first objective is to identify the six most important factors. Quality value measures are then assigned to each factor on a scale of 1 to 10. Local representatives assign importance weights to each factor. The product of the rating and weight produce environmental quality points that are summed over each area. Finally, probabilities are assigned to individual impacts and expected value is calculated by looking at the product of the relative weight, the change in wetland value, the probability of the event causing the change, the indicator base value, and the area of wetland affected. Computer maps with spatial distributions can thus be generated in reports for review. The approach has been used for the Yazoo River basin and the Neuse River estuary. While the procedure handles dynamic effects, it is weak in not accounting for indirect effects and lacks in enriching the evaluation through feedback.

The Sorenson network

Sorenson, J. (1971). "A framework for identification and control of resource degradation and conflict in the multiple use of the coastal zone," Technical Report, Dept. of Landscape Architecture, University of California, Berkeley, CA.

The Sorenson network was developed to focus on environmental costs related to land use. This method utilizes a matrix approach like some of the other methods discussed previously. It generates 55 coastal zone uses on the basis of their potential environmental impact. For each land use, a variety of factors must be measured in the matrix. The originality of the approach is the incorporation of a network model associated with the matrix, which portrays land use interactions that occur, and their effect on cost. The network model requires a lengthy process to generate. The advantage of the approach is the ability to present factual information. However, the technique fails to go beyond the physical representation towards evaluation.

The Kane simulation model

Kane, J., Vertinsky, I., and Thompson, W. (1973). "KSIM: A methodology for interactive resource simulation," *Water Resources Research* 9, 65-80.

Kane developed a procedure for conducting systems analysis in resource management and impact assessment. The main purpose of the procedure is to clarify system interrelationships for planners and decision-makers. This is achieved by creating a model of the interrelationships of the various attributes by observing minimum and maximum variations in impact. Nine variables are identified that represent measurable elements of the system. As with other models, this procedure uses a scaling process and utilizes an interaction matrix. Interactions of pairs of variables are conducted by participants using a Delphi process. A simulation program draws measurable values from two distinct matrices, one containing long-term impacts and the other short-term impacts. The procedure has been used to develop environmental impact statements in California. The procedure does well in capturing deterministic judgements. It is a dynamic process whereby one can look at time variations by changing the matrices used in the simulation process. Nonetheless, dependency of the approach on the Delphi process limits the size of functions which may be realistically considered in a group setting.

The goal achievement matrix

Hill, M., and Alterman, R. (1968). "Power plant site evaluation: The case of the Sharon plant in Israel," *Journal of Environmental Management* 2, 179-96.

The goals-achievement methodology is used to address project evaluation schemes. This technique relies on the development of a matrix; however, it allows for the definition of important objectives in the form of quantitative monetary terms or qualitative benefits. It is structured in such a way as to allow various decision groups to assign weights to each objective. Once weights are assigned, the procedure calls for the anticipation of possible consequences that may arise as a result of impacting action plans. Impacts can be measured as point estimates of uncertainty or as ranges that represent risk values. The matrix can then be disaggregated to provide measures relating to alternative interests such as location, population groups, etc. The matrix is more powerful to the decision-maker as an overall representation of objectives, although it can also be used to evaluate weighted sums or to measure outcomes on a monetary scale. The approach has been used to access site selection for power plants. It must be noted that the validity of the technique relies heavily on the predictive approaches that are used with it (Hyman and Stiftel 1988).

The surrogate-worth tradeoff approach

Haimes, Y., and Hall, W. (1974). "Multi-objectives in water resources systems: The surrogate-worth tradeoff method," *Water Resources Research* 10, 615-24.

This approach is derived from welfare economics. The approach assumes that marginal utility can be measured by conducting comparisons of alternative sets of attributes that vary slightly and thus develop surrogate-worth functions. The technique is based on interviewing individuals who are asked to identify the utility of the various attributes within a particular ordinal scale. The method was applied in basin-wide planning for the Maumee River.

Applied decision analysis

Keeney, R., and Raiffa, H. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs*. John Wiley & Sons, New York.

Applied decision analysis is known through classical decision theory. It is heavily based upon utility theory. Of all the methodologies discussed, it is the most formally structured. In essence the analysis is initiated by identifying objectives and their related attributes. Frequency distributions are then used to project future values of the attributes for each alternative.

Preferences are next measured on a scale from 0 to 1, and a utility function is determined. This is achieved through optimization until an alternative is identified that represents the maximum utility. Examples of the use of this analysis approach, given by Hyman and Stiftel (1988) include the expansion of the Mexico City airport and the assessment of air pollution in New York. This technique continues to be used extensively.

Adaptive environmental assessment and management

Holling, C., ed. (1978). *Adaptive environmental assessment and management.* Wiley-Interscience, New York.

Adaptive environmental assessment is the least formal of all of the approaches mentioned in this annotated bibliography; however, it provides a basis for structured modeling. The objective of the technique is to be responsive to changes in decision-making and environmental considerations, and to focus upon effective fact-finding. The methodology focuses on personal contact and communication. It uses a series of workshops to develop and refine models that are representative of the domain being evaluated. As the workshops progress, the approach shifts from model generation to data collection and evaluation. The process uses sensitivity analysis to explore the implications of varying the model's boundaries. A final effort is conducted

whereby packages of information are distributed to decision-makers for evaluation.

SAGE: participant-value method for environmental assessment

Hyman, E., and Stiftel, B. (1988). *Combining facts and values in environmental impact assessment: Theories and techniques.* Westview Press, Boulder, CO.

Hyman and Stiftel developed SAGE to address many of the shortcomings they believed were present in the technologies that they reviewed. The SAGE approach is based upon social judgement theory. It tries to find more valid ways of representing broad-based groups of individuals. The central theme of their technique is to deduce value weights of individuals by analyzing the decisions that people make. Beyond this theme, the methodology follows a highly structured approach similar to that of Keeney and Raiffa (1976), yet not as theoretically refined. Their technique has been tested extensively. Their literature provides a detailed discussion of the application of SAGE for the environmental assessment of the watershed for the Falls of the Neuse River.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1995

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Dredging Research Program Benefits Analysis

5. FUNDING NUMBERS

6. AUTHOR(S)
F. H. (Bud) Griffis, Charles E. Jettmar, Sotiris Pagdadis,
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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U.S. Army Engineer Waterways Experiment Station,
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report DRP-95-8

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers, Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report presents an analysis of benefits attributable to the Dredging Research Program (DRP). Each product developed by the DRP was catalogued. Each operation and maintenance dredging project was analyzed to determine whether a DRP product has been used or could be used on that project. The project was estimated. The benefits were categorized as direct, cost avoidance, environmental enhancement, mission enhancement, and other indirect benefits. These benefits were arranged into a database. Due to uncertainty associated with each benefit estimate, each benefit estimate was assumed to follow a specific probability distribution. The sum of all benefits was then subjected to a Monte Carlo analysis and the relative frequency histogram of the final sum of all benefits was calculated. There is a 0.90 probability that the DRP will provide benefits of at least $100,586,000 from 1994 through 1998. Based on one-time noncyclical project benefits that were not included in that number, it is probably understated by 100 percent.

14. SUBJECT TERMS
See reverse.

15. NUMBER OF PAGES
97

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified		

14. (Concluded).

Direct benefits
Dredging projects
Estimates
Indirect benefits
New-work dredging
One-time benefits
Operation and maintenance
Probability
Recurring benefits
Relative frequency